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PLUS

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THE FIRST HUMAN

THE DISCOVERY THAT'S REWRITING OUR ORIGINS

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Astronauts will soon be able to eat bread on the ISS → p17

WELCOME

I have to admit I've got a soft spot for hackers. Pop culture's to blame. Novels like William Gibson's *Neuromancer* and Neal Stephenson's *Snow Crash* painted hackers as 21st-Century cowboys: mavericks and mercenaries subject to their own laws. I didn't want to be John Wayne, I wanted to be Keanu Reeves.

Of course, in the real world the picture (and actually hacking a system) is more complicated. Hackers can be heroes or villains depending on your perspective. Some want to fight the system while others are motivated by money, politics or boredom. In the wake of high-profile hacks and tragic terrorist attacks, politicians on all sides of the debate want to introduce tighter regulation on the internet. But will it work? On p38 we talk to security experts and former hackers to find out.

Meanwhile in Canada, a team of mathematicians and programmers are taking computing to a whole new level. They have created an AI that has outwitted some of the world's best poker players. The feat – beating human players at No Limit Texas Hold 'em poker – marks a step change for AI, but also a new way to use computers to solve some of the most complicated and messy problems facing science today. Read all about it on p64.

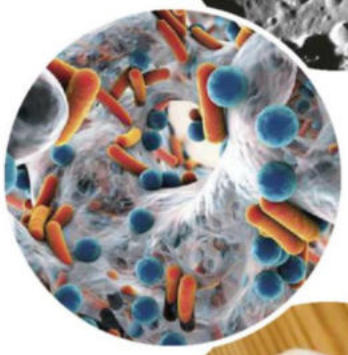
Finally, from 7-9 July, the *BBC Focus* team will be heading to Blue Dot Festival – a unique carnival of music, science and culture. We can't wait. If you're attending this year and you see me wandering around Jodrell Bank's spectacular grounds, then come and say hello.

Enjoy the issue!

Daniel Bennett, Editor

WHAT WE'VE FOUND OUT THIS MONTH

Saturn's moon Hyperion is as porous as pumice → p51



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Every one of us is taking in molecules from Caesar's last breath → p92

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JANE FRANCIS
Jane is the director of the British Antarctic Survey and has undertaken numerous expeditions to the world's polar regions. We wanted to find out more. → p98

PAUL PARSONS
Freelance writer Paul specialises in science and stats, so we sent him off to investigate the artificial intelligence that can beat the pros at poker. → p64

GOVERT SHILLING
Soon, the Cassini mission to Saturn will come to a close. Astronomer Govert takes a look at some of the craft's most exciting discoveries so far. → p48

COVER: MAGIC TORCH

CONTACT US

Advertising
neil.lloyd@immediate.co.uk
0117 300 8276
Letters for publication
reply@sciencefocus.com
Editorial enquiries
editorialenquiries@sciencefocus.com
0117 314 7388
Subscriptions
focus@servicehelpline.co.uk
0844 844 0257*
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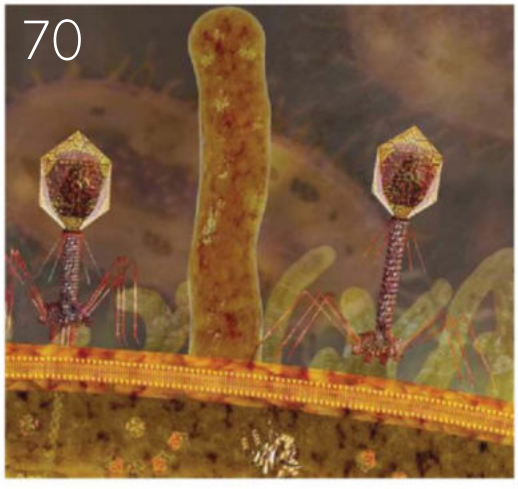

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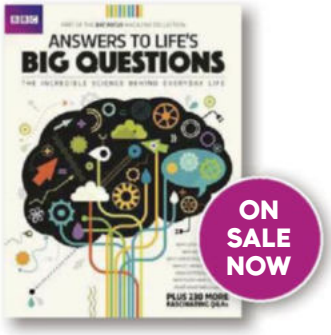
Special issue



ANSWERS TO LIFE'S BIG QUESTIONS

The latest special edition from the *BBC Focus* team explores the incredible science behind everyday life. Discover why cats hate water, why we forget, how astronauts poo, plus over 230 more fascinating facts.

Hunting machines

MONT-DE-MARSAN,
FRANCE

A golden eagle grapples with a drone in an aerial battle above an airbase in southwestern France.

Four golden eagles have been trained by the French military to tear invading drones from the sky. D'Artagnan, Athos, Porthos and Aramis (named after characters from *The Three Musketeers*) were hatched out and fed on top of drones, to create an association between food and the flying bots. It takes around eight months to train the eagles, with a chunk of meat given as a reward after each successful capture.

The unusual technique has been adopted amid worries about rogue drones being used to spy or launch attacks on French soil, after drones flew over the Élysée Palace in Paris and a restricted military site in Brittany in 2015.

The musketeers have created such a buzz that the French air force is reported to have ordered a second brood of avian allies, expected to begin training this summer.

PHOTO: GETTY

Suits you, sir!

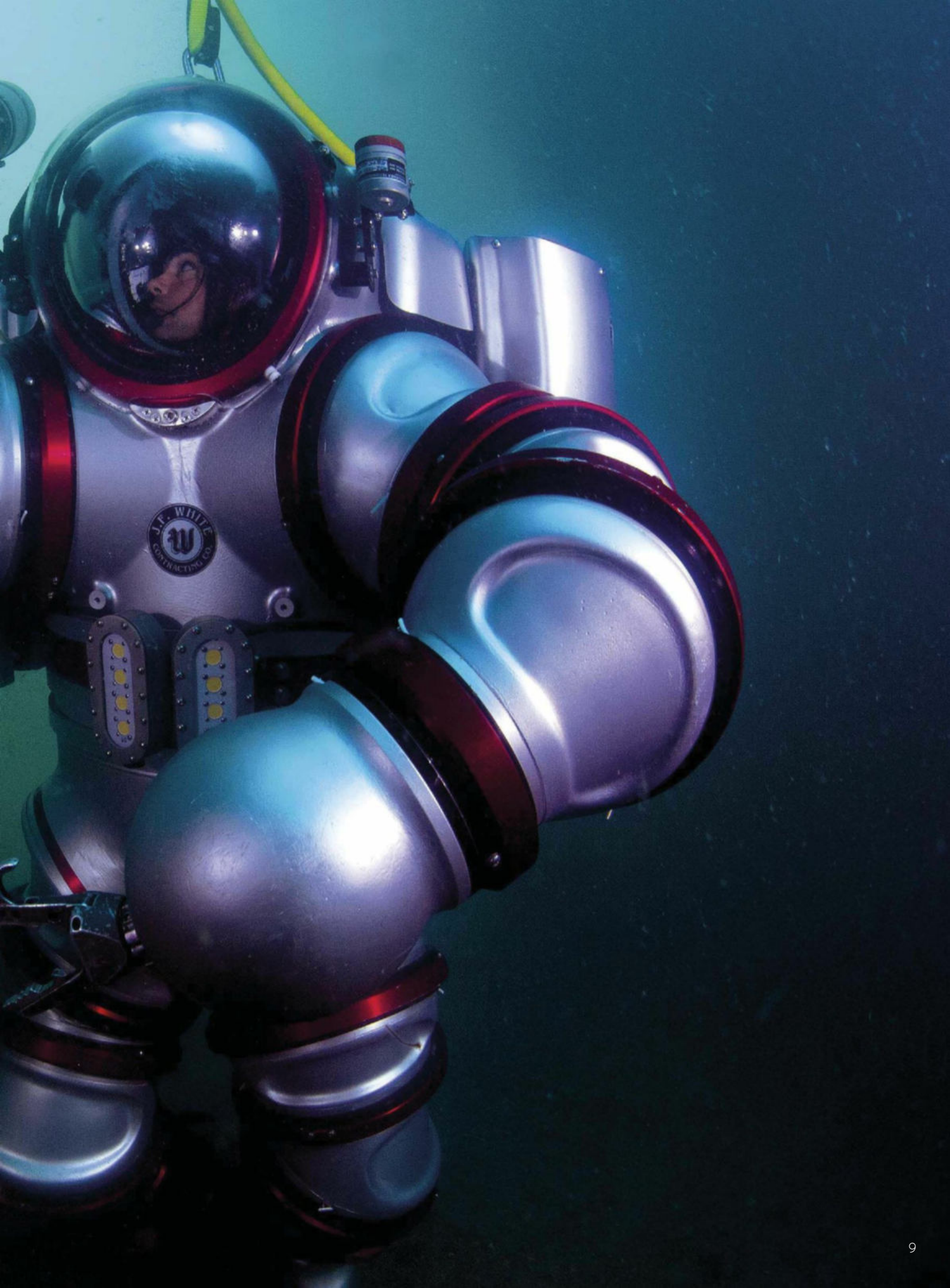
VANCOUVER,
CANADA

You won't find this snazzy little number for sale on Savile Row! Dubbed the Exosuit, this 'atmospheric diving suit' was made by Canadian undersea tech specialists Nuytco Research Ltd.

The suit is made from hardwearing aluminium and is most commonly used for construction and maintenance work in marine oilfields around the world. However, it was recently shipped to the Greek island of Antikythera to explore the wreck of a 2,000-year-old ship – the site where the mysterious mechanical astronomical device known as the Antikythera mechanism was found in 1902.

An internal pressure regulation system fitted inside the suit allows divers to reach depths of up to 300m without the risk of decompression sickness, and there's also enough oxygen on board to keep someone breathing for up to 50 hours – though dives typically don't last more than a few hours.

PHOTO: NATIONAL GEOGRAPHIC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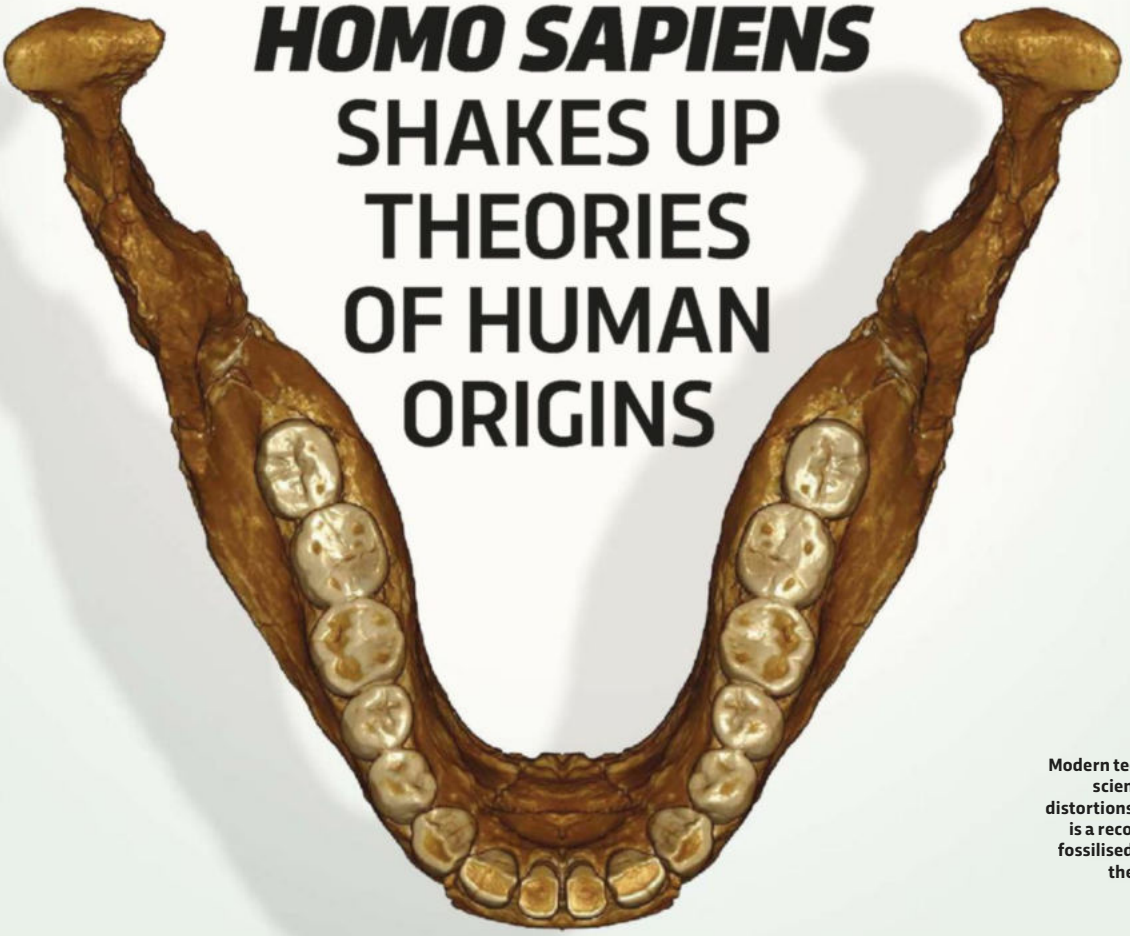
DISCOVERIES

DISPATCHES FROM THE CUTTING EDGE

SUMMER 2017 | EDITED BY JASON GOODYER

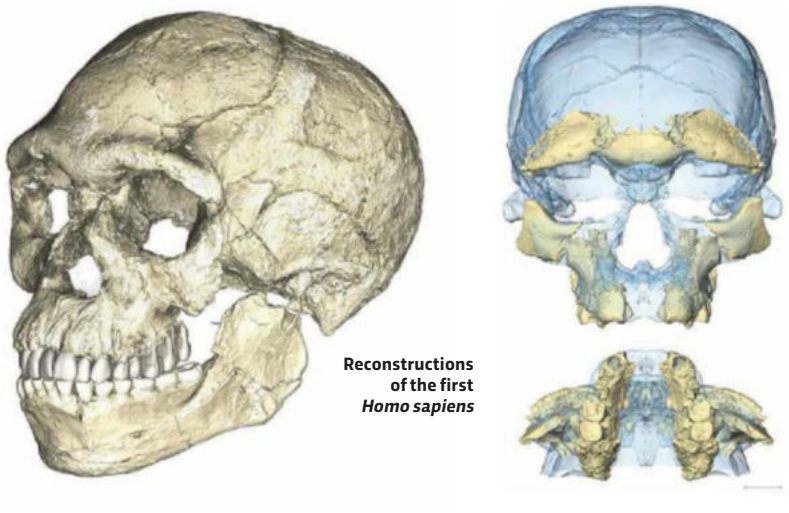
DISCOVERY OF OLDEST *HOMO SAPIENS* SHAKES UP THEORIES OF HUMAN ORIGINS



Modern techniques allow scientists to correct distortions of fossils. This is a reconstruction of a fossilised jawbone from the Moroccan site

ANTHROPOLOGY

Homo sapiens bones have been unearthed in Morocco dating back 300,000 years, challenging the idea that we first evolved in East Africa 200,000 years ago



Reconstructions of the first *Homo sapiens*

A cache of newly discovered fossils unearthed from a disused mine in Morocco has cast doubt upon the commonly held belief that *Homo sapiens* arose in East Africa 200,000 years ago.

The remains of several individuals, along with a collection of stone tools and animal bones, were found at the Jebel Irhoud archaeological site in Morocco. Using state-of-the-art dating techniques, a team at the Max Planck Institute in Leipzig estimates that the bones date back about 300,000 years, making them the oldest securely dated fossil evidence of our own species.

Previously, the oldest *Homo sapiens* fossils were found in Omo Kibish in Ethiopia and were estimated to be 195,000 years old. Until now, it was widely believed that all humans descended from a population that lived in East Africa around 200,000 years ago.

"We used to think that there was a cradle of mankind 200,000 years ago in East Africa, but our new data reveal that *Homo sapiens* spread across the entire African continent around 300,000 years ago. Long before the out-of-Africa dispersal of *Homo sapiens*, there was dispersal within Africa," said researcher Prof Jean-Jacques Hublin.

The team used highly accurate 3D scans and statistical shape analysis based on hundreds of measurements to show that the facial shape of the Jebel Irhoud fossils is almost indistinguishable from that of modern humans. However, they found that the craniums of the Jebel Irhoud fossils have an elongated braincase – a feature more common in early *Homo* species.

"The inner shape of the braincase reflects the shape of the brain," said researcher Dr Philipp Gunz. "Our findings suggest that modern human facial morphology was established early on in the history of our species, and that brain shape, and possibly brain function, evolved within the *Homo sapiens* lineage."

"North Africa has long been neglected in the debates surrounding the origin of our species," said researcher Abdelouahed Ben-Ncer. "The spectacular discoveries from Jebel Irhoud demonstrate the tight connections of the Maghreb [a region of northwestern Africa] with the rest of the African continent at the time of *Homo sapiens'* emergence."

A fossilised jawbone from the oldest *Homo sapiens*

"NORTH AFRICA HAS LONG BEEN NEGLECTED IN THE DEBATES SURROUNDING THE ORIGIN OF OUR SPECIES"

EXPERT COMMENT

Chris Stringer and Julia Galway-Witham

Researchers at the Natural History Museum

Until recently, most experts thought that modern humans had evolved between 150,000 and 200,000 years ago, with the earliest known fossils found at sites in Ethiopia. It was not until new research was published in *Nature* in June that we have compelling fossil evidence to suggest that the evolution of our lineage is deeper rooted than previously thought, and not confined to East Africa.

Now dated to about 300,000 years ago, the assemblage of human fossils from Jebel Irhoud represents the earliest known examples of *Homo sapiens*. However, it is not yet known how peripheral the Irhoud population would have been. Populations of *H. heidelbergensis*, *H. rhodesiensis* and *H. naledi* were living contemporaneously in central and southern Africa and it is likely that there were other populations of early *H. sapiens* elsewhere in Africa at this time. In light of this new chronology, and combined with the mixture of traits in the Irhoud fossils, it's possible that still earlier fossils from sites in Morocco and Tanzania might represent an even more primitive form of our species.

While molecular evidence suggests the ancestors of modern humans may have diverged from Neanderthals at least 500,000 years ago, and early Neanderthals from 430,000 years ago have been identified from Sima de los Huesos in Spain, equivalent specimens from the modern human lineage had yet to be identified. The Irhoud fossils are contenders for this position. The clear anatomical differences between the Irhoud and Sima specimens suggest the two lineages were diverging rapidly, even though they lie relatively close to the date of their projected common ancestor. Intriguingly, both the Sima and Irhoud fossils do not display the full suite of features present in later representatives of their respective species. This has interesting implications for understanding how and in what order these anatomical features evolved over the last half a million years.

PHOTOS: TERESA STEELE/UC DAVIS, SARAH FREIDLINE/MPI EVA LEIPZIG

Clearly, this new frog species is awesome

ZOOLOGY

NEWLY DISCOVERED FROG HAS A VISIBLE HEART

We've all heard the expression 'wearing your heart on your sleeve', but few of us can pull off that trick with the aplomb of a newly discovered species of frog. The tiny amphibian's heart is clearly visible at all times, thanks to the translucent skin on its chest.

The frog, which measures just 2cm in length, has been named *Hyalinobatrachium yaku*, and it has just been described for the first time in a paper published in the journal *ZooKeys* by a team of scientists led by Juan M Guayasamin from Ecuador's Universidad San Francisco de Quito. It falls into a family of frogs called Centrolenidae, or 'glass frogs', all of which have translucent skin on their abdomen that renders their liver, stomach and intestines visible. In *H. yaku*, however, this translucence extends to the chest area, putting the frog's heart on view.

All known Centrolenidae species are native to Central and South America, and *H. yaku* is no different, with three populations discovered in Ecuador. As these three populations are quite widely dispersed, lying some 110km from each other, it's believed the frog may make its home across a much wider swathe of Ecuador and neighbouring Peru.

Intriguingly, the three populations of *H. yaku* so far discovered exhibit varying behavioural characteristics. In two areas, they have been found only on the underside of leaves hanging a metre or so above shallow, slow-moving streams. However, in the third area, the frogs were located on the leaves of small shrubs and ferns lying more than 30m from the nearest water source.

PHOTOS: JAMIE CULEBRAS/ROSS MAYNARD, NASA

SPACE

FIVE THINGS WE'VE JUST FOUND OUT ABOUT JUPITER

NASA's Juno mission, which was launched in 2011 and has been in orbit around Jupiter since July 2016, has just sent back its first science results. Here are the key findings…

1. IT'S GOT A STRANGE MAGNETIC FIELD

Jupiter's magnetic field is stronger than expected at 7.8 Gauss – that's 10 times stronger than any magnetic field found on Earth. It's also quite uneven, suggesting that it may be mostly generated quite close to the surface.

2. THE POLES ARE STORMY, AND QUITE DIFFERENT FROM EACH OTHER

Juno scientists found that, towards Jupiter's poles, regular bands of gases give way to chaotic, swirling storms. What's not yet known is the mechanism that drives these storms, or why this activity is not the same at both poles.

3. JUPITER'S 'NORTHERN LIGHTS' AREN'T LIKE EARTH'S

Just like Earth, Jupiter is home to auroral activity caused by interaction between its upper atmosphere and the solar wind. However, the exact processes involved in their formation appear to be different on Jupiter than on Earth.

4. THE COLOURED 'BELTS' GO DEEPER THAN EXPECTED

For years, the scientific consensus has been that the coloured bands visible on Jupiter's surface represent only the planet's cloud tops. Juno, however, has found that some of these bands penetrate at least 350km into the planet – and potentially even deeper.

5. THERE'S STILL A LOT MORE TO LEARN

"We knew going in that Jupiter would throw us some curves," said Juno principal investigator Scott Bolton from the Southwest Research Institute in San Antonio, Texas. "But now we are finding that Jupiter can throw the heat, as well as knuckleballs and sliders. There is so much going on that we didn't expect, that we have had to begin to think of this as a whole new Jupiter."

IN NUMBERS

2060

The year that AI will be able to do everything better than humans, according to a survey of experts carried out by the Machine Intelligence Research Institute in California.

4,600 KELVIN

The surface temperature of planet KELT-9b. This is the highest temperature ever recorded on a planet.

50.7 PER CENT

The amount of UK power supplied by wind, solar, hydro and wood pellets on 7 June – the first time more energy was generated by renewables than fossil fuels.

PHOTOS: GETTY X2

WHAT DOES THE WITHDRAWAL OF THE US FROM THE PARIS AGREEMENT MEAN FOR CLIMATE CHANGE?

On 22 April 2016, in an attempt to prevent global temperatures from raising to 2°C above pre-industrial levels, the world's largest emitters of greenhouse gases banded together to strike the Paris Agreement. It was a shining example of global cooperation, that is, until US president Donald Trump indicated in June that the US will be pulling out.

If all countries implemented their commitments under the agreement, global greenhouse gas emissions would peak over the coming decade before returning to close to their current level in 2030. Global temperatures would still be rising, but at a constant rather than an exponentially increasing rate if nothing were to be done. Crucially, the agreement accepts that to stop the warming, net global emissions need to be reduced to zero. It also sets up a mechanism for progressively more ambitious reductions through a periodic 'stocktake', with the first scheduled to be completed in 2023. Right now, the US accounts for about 12 per cent of global emissions, but if other countries cut back while the US keeps its carbon footprint stomping along at a steady 'business as usual' clip, then that fraction will rise. The result: we will never reduce emissions to zero, and temperatures will keep rising.

It's difficult to quantify exactly what the US withdrawal might mean on a global level, but a back-of-the-envelope calculation estimates the net result being a 0.3°C rise by the year 2100. This might not sound like much, but in our delicately-balanced world, it is.

Increased temperatures cause fluids to expand. This, combined with the melting of land-locked ice, leads to ocean levels rising, engulfing any low-lying coastlines. This is particularly concerning to small island states such as the Maldives and Fiji. In fact, it was the coalition of these very states that, among others, recognised the difference that 0.5°C could make. They pushed hard to get the Paris Agreement signed up to limit climate change to a 1.5°C rise, rather than the original suggestion of 2°C. The absence of the US from the Paris Agreement might take us dangerously close to the latter.

Even for those lucky enough to live away from low-lying coastlines, the situation is still far from ideal; let us consider, for example, how heat waves might affect us now that the US is out of the fold. In the Mediterranean, we know that 0.3°C average increase in global temperature would lead to a 0.5°C increase during extreme heat waves. In cities, the increased warming is likely to be far larger due to trapped heat – the 'urban heat island effect'. Even this relatively small increase in heat stress can tip our bodies over the edge, leading to heat stroke and cardiovascular failure. In Paris, this could lead to approximately 20 additional deaths during each summer. Scale this up to the hundreds of cities that are impacted by a single heat wave and you suddenly have a serious public health issue. Of course, heat stress isn't confined to humans, as plants and animals are also affected. This could have serious ramifications for agriculture, global food distribution, and the natural world in general.

Perhaps one of the largest areas of uncertainty in climate change is tipping points – points at which irreversible change takes place. The concept was explored in the film *The Day After Tomorrow* in which Dennis Quaid gave an excellent portrayal of a climate scientist who accurately predicted when such a tipping point would occur. However, the reality is that quantifying exactly how much the temperature must rise to reach a point of no return is extremely difficult. There are a number of potential tipping points that could lead to global catastrophe, yet we are uncertain how far we can push the Earth's climate system before they occur. One thing that is clear is that once such a point is breached, there's no going back. Therefore, surely it's best that we do our utmost not to give Hollywood any more reasons to make another climate-related disaster movie.

Demonstrators were angry about Donald Trump's withdrawal from the Paris Agreement

Dann Mitchell is a climate scientist at the University of Bristol. He studies the impacts of climate change.

The researchers accurately reconstructed faces by analysing brain activity in rhesus macaques

NEUROSCIENCE

PHOTOS OF FACES RECREATED FROM MONKEY BRAIN SIGNALS

Did you know that every picture in *BBC Focus* is made up from just four colours (or three, if you're reading our digital edition)? By varying the proportions of cyan, magenta, yellow and black ink, printers can recreate almost any colour you can imagine. And now it seems our brains may process faces in similar fashion – by analysing each face in terms of its relative 'amounts' of 50 different variables.

Neuroscientists at California University of Technology (Caltech) used statistical analyses to identify 50 variables representing the differences between faces. Each of these complex variables can be imagined as a spectrum, or sliding scale – for instance, with a low hairline and close-set eyes at one end, and a high forehead and widely spaced eyes at the other. The researchers then showed 2,000 photos of faces to two macaque monkeys while monitoring their brain activity. They identified some 205 neurons in the temporal lobe that fire in response to seeing faces, and recorded the rate of activity for each cell.

By mapping these rates to positions on the 50 previously identified facial characteristics spectra, they were able to generate computer images that were uncannily similar to the original photos.

"It was a complete surprise," said Prof Doris Tsao, co-author of the paper in the journal *Cell*. She went on to point out that the findings don't necessarily contradict previous research which has suggested that particular neurons in the hippocampus 'remember' particular faces. "These cells are coding coordinates, and you can use these coordinates for anything you want. [Or] you can build up a lookup table that codes these into specific identities."

ACTUAL FACE

PREDICTED FACE

PHOTOS: GETTY, ESO, TSAO LAB/CALTECH. ILLUSTRATION: DANIEL BRIGHT

SPACE

KEY INGREDIENT FOR LIFE FOUND AROUND INFANT STARS

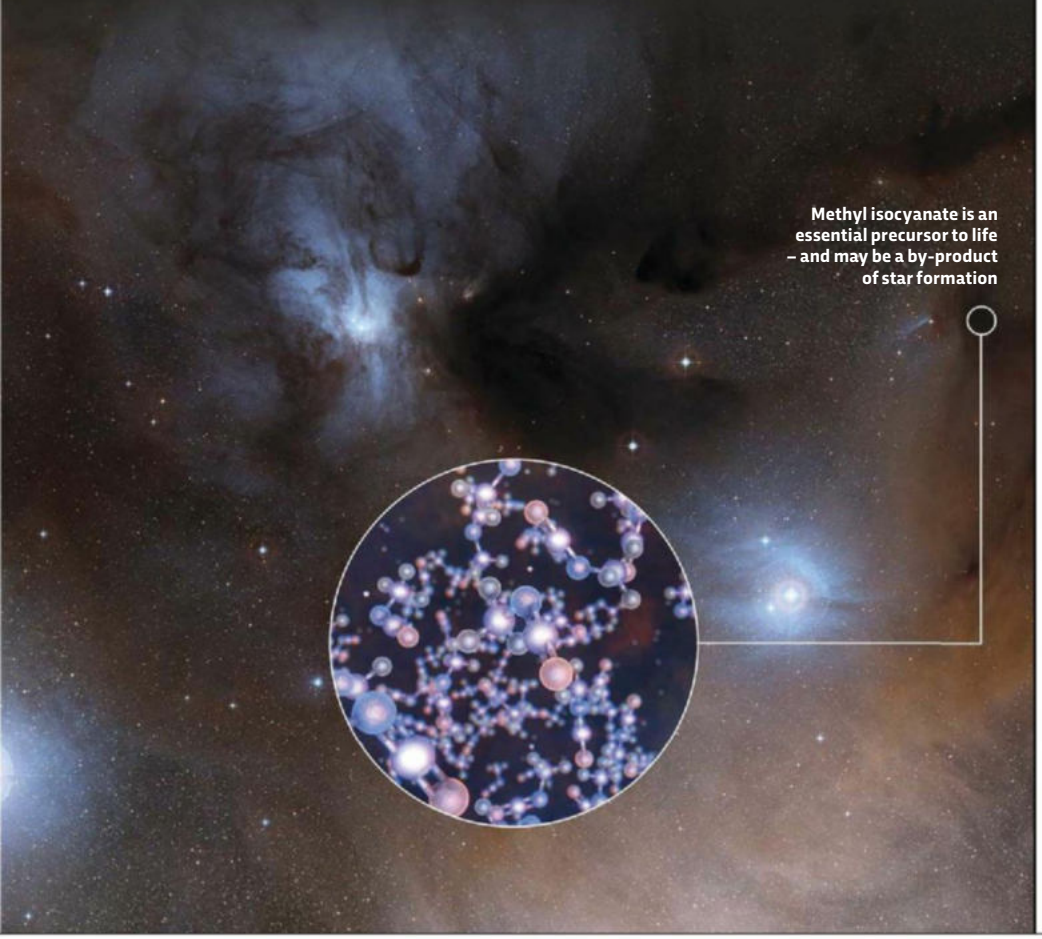
Did life on Earth begin in the Sun? Methyl isocyanate, a vital ingredient for life that is involved in the synthesis of the peptides and amino acids that form proteins, has been found in a region where infant, Sun-like stars are being formed.

Molecules of methyl isocyanate were detected in the multiple star system IRAS 16293-2422 by two teams of astronomers using the ALMA (Atacama Large Millimeter/submillimeter Array) telescope in Atacama, Chile. IRAS 16293-2422 is a region of intense star-forming activity that lies some 400 light-years from Earth, in the constellation of Ophiuchus. The compound's unique chemical fingerprint was detected in dense inner regions of the cocoon of dust and gas that surrounds very young stars.

"These protostars are very similar to the Sun at the beginning of its lifetime, with the sort of conditions that are well suited for Earth-sized planets to form," said researcher Rafael Martín-Doméneach. "By finding prebiotic molecules in this study, we may now have another piece of the puzzle in understanding how life came about on our planet."

Tantalisingly, the team's measurements suggest the chemicals essential for life may be found throughout the Universe.

"Our lab experiments show that methyl isocyanate can be produced on icy particles under very cold conditions similar to those in interstellar space," said researcher Niels Ligterink. "This implies that this molecule is likely to be present near most young solar-type stars."



Methyl isocyanate is an essential precursor to life – and may be a by-product of star formation

MUSICIANS

Playing a musical instrument can help to keep your brain in shape in old age, researchers in Canada have found. The effect is thought to be due to the fact that playing an instrument requires many brain systems to work together.

SARNIE-LOVING SPACEMEN

Bread is a no-no on the ISS because crumbs can wreak havoc with delicate machinery. But now the German Bake in Space project has produced a special dough that produces crumb-free bread.

GOOD MONTH

BAD MONTH

MIND WANDERERS

Those who struggle to focus on the task in hand are less likely to maintain perseverance and passion in their long-term goals, researchers at the University of Waterloo have found. Now, what was I just doing...?

PRIESTS

Holy macaroni! German engineers have created a robot priest. Dubbed BlessU-2, the bot can administer blessings in five languages. It was built for an exhibition about the history of the church, and is designed to spark debate about its future.

HEALTH

"This viral immunotherapy appears to be more potent than others that have been before"

A team has created designer viruses that help the immune system target tumours. One of the researchers, Prof Daniel Pinschewer, *describes this new approach to cancer therapy*

ABOVE: **Immunotherapy uses the body's immune system to tackle disease. Here, a T-cell (purple) has been engineered to attack a cancer cell (red)**

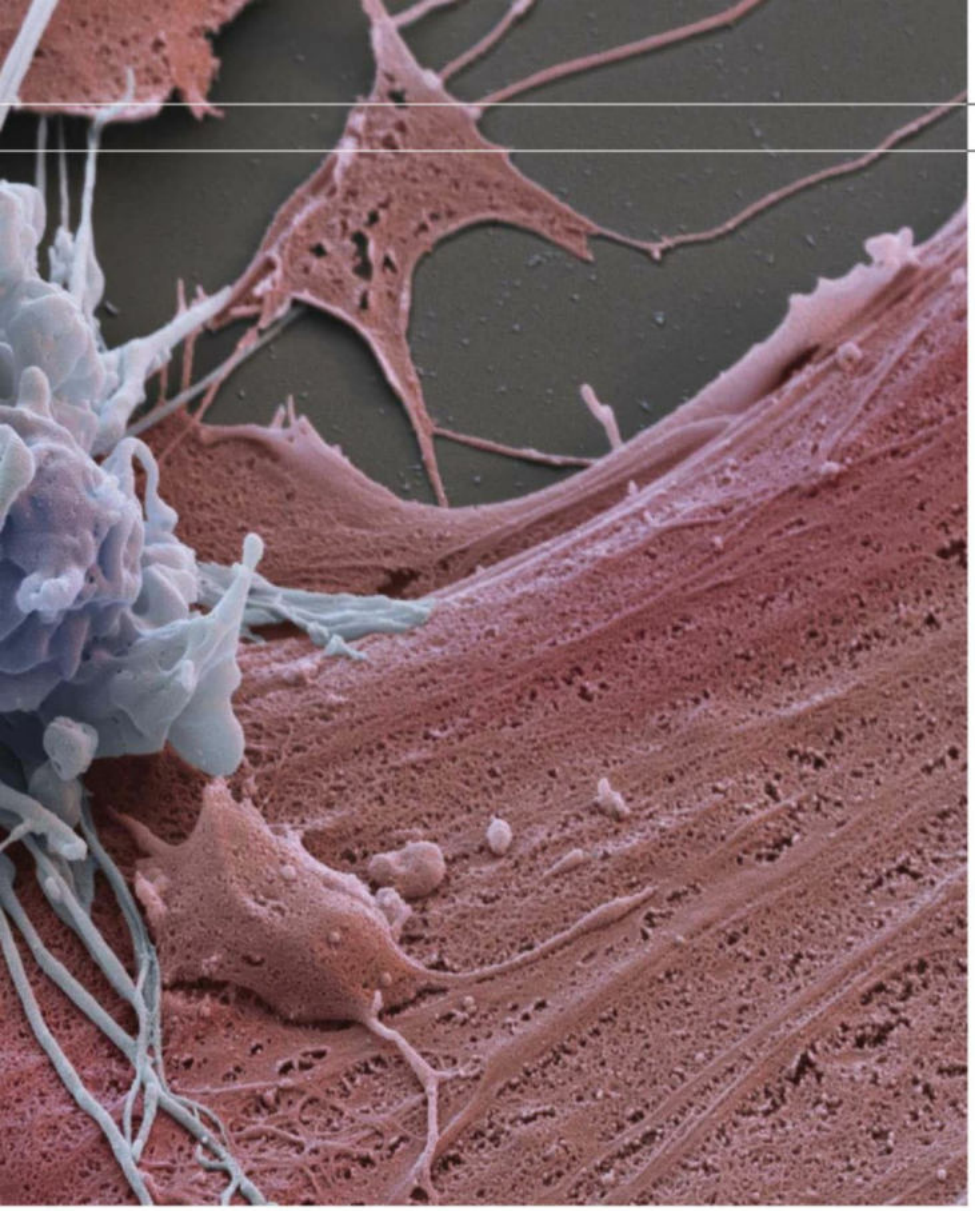
What is 'immunotherapy'?
Chemotherapy uses a chemical not normally present that's toxic and more deadly to cancer cells than to other cells. Radiotherapy involves dosing ionising radiation onto cancerous parts. In contrast, immunotherapy describes any approach that leverages the body's own defence system in combating cancer. There are several different types of immunotherapy. The most commonly known is antibodies that are injected – they unleash the immune system. This takes the foot off the brake, so the lukewarm response the body usually mounts against cancers gets intensified. But this is not specific, so any response is strengthened, including responses that can make you sick. That's a downside.

How does your therapy work?
We haven't yet trialled in humans, but the approach we're pursuing is to give a patient a virus that causes an infection like a common cold. The virus is equipped with a component of the tumour that a patient – or in our case, the tumour-bearing mouse – had. That creates awareness in the defence system. Our immune defence has been shaped over millions of years to fight viruses and bacteria, and now it gets to see a piece of the cancer in this context, so it will launch a fierce fight against all the elements it sees as a virus. It treats cancer cells as if they were virus-infected.

Which virus do you use?
We're using lymphocytic choriomeningitis, a virus that almost exclusively infects mice. It can be accidentally transmitted to humans and normally only causes a common cold-like illness, so nothing serious. It's not dangerous to an extent that one could not justify giving it to a cancer patient. However, we have engineered these viruses to be 'attenuated', which means their ability to make mice sick is reduced. Therefore, the virus grows more slowly than the wild virus would.

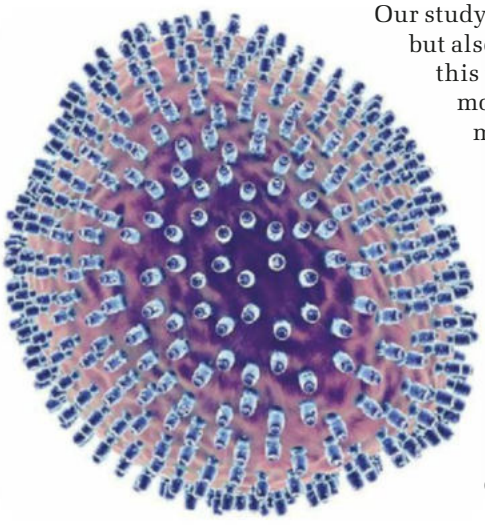
Which cancers could you target?
In principle any cancer could be targeted, but for each type you have to tailor-make a virus. You need to identify a target, a molecular hallmark of that cancer, then build it into your virus. We know there are specific components that identify cancers and would not be present in

PHOTOS: SCIENCE PHOTO LIBRARY X2. ILLUSTRATION: DAN BRIGHT



normal cells, otherwise you would instruct your defence to attack a healthy tissue of your body. Then we create a virus. We do this by gene technology, out of its building blocks, then grow it in a cell culture in the lab. We have an industrial partner and we're counting on having the first patients treated within two years.

BELOW: **The lymphocytic choriomeningitis virus that Pinschewer's team is using to study immunotherapy**



What makes your approach better than others?

Our study not only describes the technology, but also describes the mechanism of *why* this viral immunotherapy appears to be more potent than others before. In mice, we have shown that commonly used viral technology failed, whereas ours was successful. This was due to the fact that our viruses, being replicating, are causing a mild infection – it's not just injecting a drug that doesn't amplify itself. This infection triggers specific molecular alarm bells, which only render the immune response potent enough to effectively combat cancer.

THEY DID WHAT?!

MOUSE POO TURNED BLUE

What did they do?

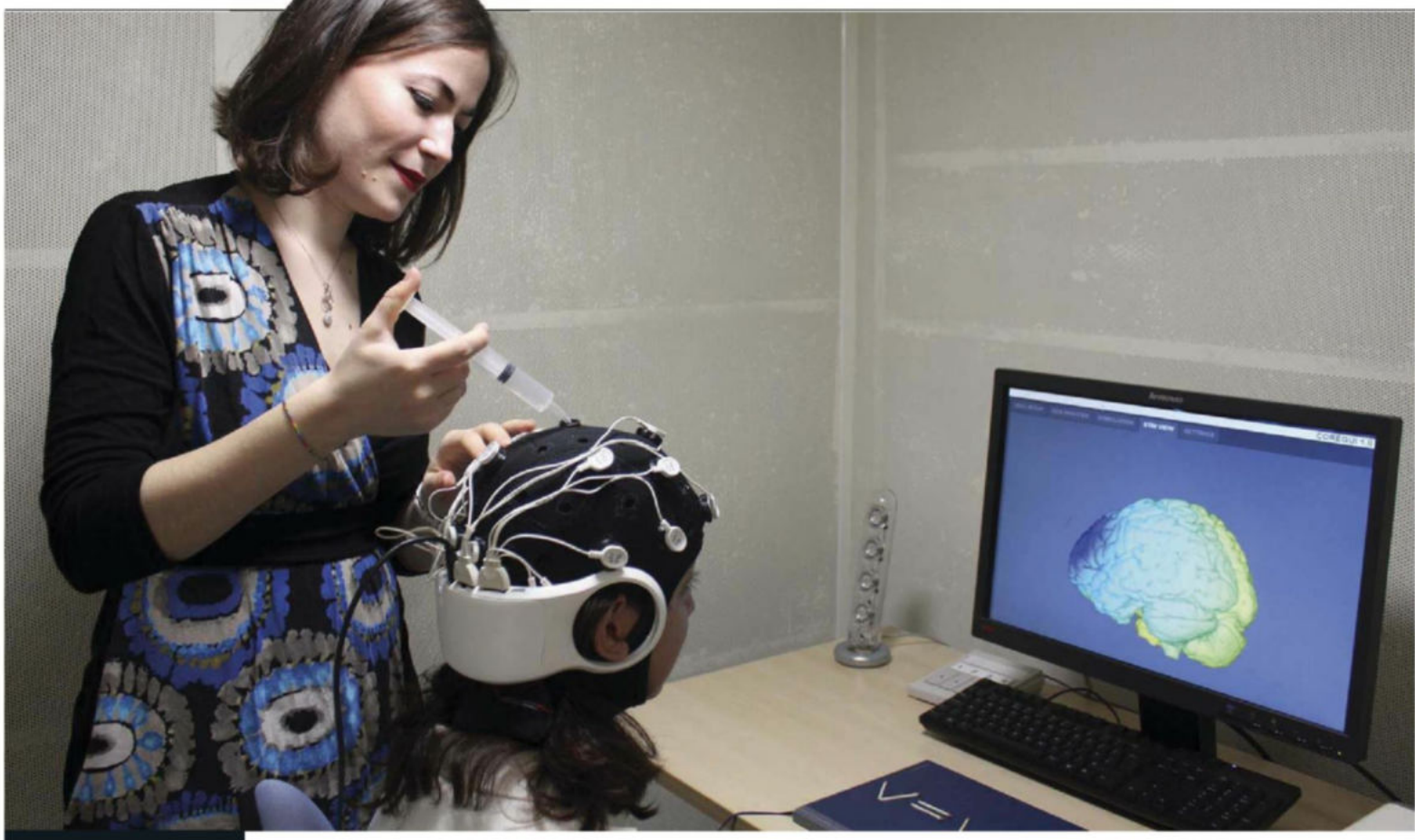
A team at Harvard Medical School engineered gut bacteria in a group of mice to turn their poo blue when they are in the presence of disease.

How did they do that?

They engineered a harmless strain of *E. coli* bacteria to produce a particular enzyme when it came into contact with tetrathionate – a substance seen in high levels in the guts of people with ulcerative colitis. They were then able to identify the enzyme in the animals' stools using a test in which it changes colour.

Why did they do that?

Understandably, many people aren't exactly thrilled when they hear the words "You're going to need an endoscopy". However, there are currently few alternatives when it comes to diagnosing gut disorders. The team hopes that their technique can be used in place of uncomfortable and intrusive cameras to check for gut illnesses in those feeling a bit, er, off colour.



NEUROSCIENCE

To stimulate the brain, electrodes are soaked in saline before being attached to the scalp

CREATIVITY BOOSTED WITH ELECTRIC BRAIN STIMULATION

Struggling to get your creative juices flowing? A team from Queen Mary University of London may have a solution – zap your brain with a blast of electricity.

The researchers found that temporarily suppressing the activity of the left dorsolateral prefrontal cortex (DLPFC), an area of the brain involved in most of our thinking and reasoning, can boost our ability to "think outside the box".

They used a technique called transcranial direct current stimulation (tDCS), to pass a weak electrical current through electrodes positioned on the head to alter the function of the DLPFC. Depending on the direction of the current flow, DLPFC was either temporarily suppressed or activated. When it was suppressed, the participants performed better at 'matchstick problems' – puzzles involving the rearrangement of geometric patterns of matchsticks designed to test lateral thinking.

"We solve problems by applying rules we learn from experience, and the DLPFC plays a key role in automating this process," said researcher Dr Caroline Di Bernardi Luft. "It works fine most of the time, but fails spectacularly when we encounter new problems which require a new style of thinking – our past experience can indeed block our creativity. To break this mental fixation, we need to loosen up our learned rules."

However, the boost in creativity came at a cost, as the participants got worse at solving problems that demanded a better use of memory.

"These results are important because they show the potential of improving mental functions relevant for creativity by non-invasive brain stimulation methods," said Luft. "However, our results also suggest that potential applications of this technique will have to consider the target cognitive effects in more detail rather than just assuming tDCS can improve cognition as claimed by some companies which are starting to sell tDCS machines for home users.

"I would say that we are not yet in a position to wear an electrical hat and start stimulating our brain hoping for a blanket cognitive gain."

PHOTOS: QUEEN MARY UNIVERSITY OF LONDON, JARED THOMAS

Before this discovery, the oldest mushroom fossils had been found encased in amber

FOSSILS

WORLD'S OLDEST MUSHROOM FOSSIL DISCOVERED

You certainly wouldn't want this turning up in your risotto ai funghi: researchers from the University of Illinois have found a mushroom fossil that's 115 million years old – the oldest discovered to date.

The ancient fungus began life on supercontinent Gondwana but ended up in northern Brazil when the Earth's tectonic plates shifted. Somehow it made its way to the bottom of a salty lagoon where it was covered in many layers of fine sediment. In time, its tissues were replaced by pyrite, or fool's gold, which later mineralised into goethite to create the fossil.

"Most mushrooms grow and are gone within a few days," said researcher Sam Heads, who discovered the mushroom when digitising a collection of fossils from Brazil. "The fact that this mushroom was preserved at all is just astonishing. When you think about it, the chances of this thing being here – the hurdles it had to overcome to get from where it was growing into the lagoon, be mineralised and preserved for 115 million years – have to be minuscule."

The fungus was about five centimetres tall and had gills under its cap, similar to a modern-day button mushroom.

"Fungi evolved before land plants and are responsible for the transition of plants from an aquatic to a terrestrial environment," said researcher Dr Andrew Miller. "Associations formed between the fungal hyphae [branching filaments that form the fungus] and plant roots. The fungi shuttled water and nutrients to the plants, which enabled land plants to adapt to a dry, nutrient-poor soil, and the plants fed sugars to the fungi through photosynthesis. This association still exists today."

WHAT WE LEARNED THIS MONTH

WATER IS SOUR

Water doesn't taste of anything, right? Wrong. Researchers at Caltech have found that drinking pure water activates the sour taste receptors in mice.

JUPITER IS THE OLDEST PLANET IN THE SOLAR SYSTEM

The solid core of Jupiter formed just a million years after the Sun, making it almost 4.6 billion years old and about 55 million years older than Earth, a team at Lawrence Livermore National Laboratory has found.

MAKING ART MAKES US HAPPY

Drawing and doodling cause an increase in blood flow in the prefrontal cortex – an area associated with the brain's reward circuit, researchers at Drexel University have found. Somebody pass the crayons.

THE NUCLEAR OPTION

Why we should learn to stop worrying and love the nuclear reactor

Few will lose sleep over news that the Three Mile Island nuclear plant in Pennsylvania, scene of the worst nuclear accident in US history, is to close.

What happened there on 28 March 1979 showed the world how small things count for a lot when it comes to nuclear safety. A single faulty valve and some dodgy instrumentation led to one of the plant's reactor cores melting, resulting in the release of radioactive material, and almost 200,000 people fleeing the area.

Many of them probably feared they were about to witness the so-called China Syndrome, where the incredibly hot reactor core burns through its containment vessel, then the ground beneath – and doesn't stop until it emerges somewhere in China. That sounds like some ludicrous scenario for a Hollywood disaster movie – and that's exactly what it is. Just days before the 'TMI' accident, cinemas in the US began screening a movie called *The China Syndrome*, about a nuclear plant that goes out of control… because of faulty equipment and misleading instruments.

Nuclear industry experts dismissed the plot as fanciful. One even told the *The New York Times* he simply did not believe a serious accident could ever happen. As statements by the nuclear industry go, that's right up there with its claim in the 1950s that it would one day produce electricity "too cheap to meter".

While the China Syndrome might be nonsense, TMI proved to be a real-life disaster for the nuclear industry. Construction of new plant in the US had already slowed through falling demand for energy and – ironically – the punitive cost of all the safety measures. TMI stopped projects dead. Over 100 orders for new reactors were cancelled, and not a single new power plant was built in the US until 2013.

In the intervening years, opponents of nuclear power seemingly saw their case bolstered by the disasters at Chernobyl in 1986 and Fukushima in 2011. But something else happened as well. Some of the best-known names in the environmentalist movement – James Lovelock, George Monbiot and Stewart Brand among them – came out as advocates of nuclear power. Their argument was simple. Yes, nuclear energy is potentially dangerous, but the 'disasters' have to be put in context. They took place in plants based on obsolete designs, and in the case of TMI and Fukushima the radiation released killed no one.

"NUCLEAR POWER IS PREFERABLE TO FOSSIL FUELS ON EVERY MEASURE"

According to international estimates, the Chernobyl disaster will eventually lead to 4,000 premature deaths. A terrible toll, to be sure – but far smaller than the WHO estimate of seven million deaths due to fossil fuel-generated air pollution each year. As Monbiot pointed out in his *volte-face*, nuclear power is preferable to fossil fuels on every measure, from global warming potential and local pollution to industrial energy – and, yes, fatalities. Most importantly of all, it's a vital source of reliable, carbon-free energy.

But what about all the deadly nuclear waste, produced in huge quantities even if nuclear power stations don't explode? Safe methods for dealing with that were developed decades ago, prompting Lovelock to declare he'd be happy to store even the worst stuff in his garden. These brave dissenters believe today's nuclear technology has a key role to play its part in combating climate change. And that means calling out the imaginary threats and wildly exaggerated accounts of real ones.

But now, just when we need it most, nuclear power is facing its biggest threat yet. It's the reason Three Mile Island will close in 2019, and no replacement built: soaring production of far cheaper shale gas and oil – ie, carbon-rich fossil fuels.

It's hard to believe that's where the eco-warriors wanted the world to be, 40 years after TMI, but that's where we are. Way to go, guys.

ILLUSTRATION: DANIEL BRIGHT

Robert Matthews is visiting professor in science at Aston University, Birmingham.

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*SimplifyDigital customers save on average £322 a year. Data based on 4,342 SimplifyDigital records between July – September 2016.

WHEELY GOOD

Seen here is the Smacircle S1, which is being touted as the world's lightest and most portable electric bike. It weighs less than 7kg and will fit into a backpack when folded up. Its handlebars feature a dock for your smartphone, which will then act both as a speedometer and as a digital 'key', preventing anyone but you from riding the bike. Boasting a top speed of 20km/h (12mph), the carbon-fibre bike can travel up to 20km (12 miles) on a single two-hour charge, and is able to carry passengers weighing up to 100kg. It's already exceeded its Indiegogo funding target nearly five times over, and will start shipping in October.

Smacircle S1, £1,300, smacircle.com

1

2

3

4

5

WANTED

1

BEST OF BOTH WORLDS

Fujifilm's new Square SQ10 is a hybrid digital/instant camera that uses a 1/4-inch CMOS sensor to take pictures, but then prints them out for you there and then. Images can be stored on a microSD card for uploading to the internet later.

Fujifilm Square SQ10, £249, fujifilm.eu/uk

2

WHAT A NUTTY IDEA!

The 5cm-long SleepPeanut sits on top of your mattress and uses motion and body heat sensors to monitor your sleep cycles during the night. It then sends that data via Bluetooth to an accompanying app, and it also has a built-in alarm clock function.

Sen.se SleepPeanut, €29 (£25 approx), sen.se

3

DIDDY DRONE

Drone maker DJI's latest baby is the Spark, a tiny quadcopter that's about the size and weight of a drinks can. Built for taking selfies, it sports a camera that is able to shoot 1080p video and 12MP stills, and can be controlled by palm gestures.

DJI Spark, £385, dji.com

4

NIGHT WATCHMAN

Nest's latest home security camera offers enhanced night vision, an 8MP sensor and a 130° field of view. It will automatically zoom in on areas where movement is detected, and is equipped with Google's FaceNet face recognition technology.

Nest Cam LQ, £299, nest.com

5

BLAST FROM THE PAST

Nuvitron's Bluetooth speaker combines 21st-Century streaming technology with a wooden body, an internal wooden waveguide and a vintage-style steel soundhorn. Differently shaped Edison and Bell models are also available.

Nuvitron Bluetooth Sound Machine Marconi, $299 (£230 approx), nuvitron.com

6

SUB MISSION

This tethered underwater drone is small enough to pack in a suitcase and comes with either a 1080p still camera or a 4K video camera. It is submersible to 100m for up to three hours, with a horizontal range of 30-500m, depending on the model.

Gladius, $1,400-$2,275 (£1,085-£1,765 approx), bit.ly/2qXxGjt

6

HAPPY CAMPERS

Have you sworn off camping after nightmares involving leaky tents, icky coffee and evil beds? Maybe this high-tech gear will change your mind…

↑ CINCH POP-UP TENT

Pitch up in mere minutes with this four-man pop-up tent that springs to life out of its bag. Solar panels keep a battery pack charged up, which you can use to power lanterns and charge your gadgets. Additional kit like LED tent pegs, reflective guylines and a mirror that hangs from the frame make this the smartest tent we've seen.

£270, cinchpopuptents.com

EASYCAMP TEMPEST 500 INFLATABLE TENT →

Thanks to its inflatable poles, this five-man tent takes less than 15 minutes to pitch. The windows, complete with toggled curtains, let in plenty of light and give it a 'home-from-home' feel. When packed, it measures almost a metre in length and weighs 15kg, so take a trolley if you're planning on hauling it more than a short distance.

£549.99, easycamp.com

ACCESSORIES

FILSON HERITAGE SPORTSMAN BAG →

Filson bags don't come with a lot of tech, but this is the only bag we've heard of that could outlive you, as every one comes with the company's lifetime guarantee. The robust, water-repellent canvas, wide straps and thick leather make this bag feel equally at home on the campsite as in the office.

$395 (£309 approx), filson.com

WACACO MINIPRESSO →

Compact and nattily designed, this portable espresso maker is just the ticket for the coffee-loving camper. It uses a nifty pump to produce the pressure needed to make a proper espresso and produces a rich, smooth-tasting cup of joe. Don't rest it on its side after using it like we did, or you might end up with coffee dregs all over your sleeping bag.

£50, wacaco.com

CRUA TRI TENT ↑

Wave goodbye to a disrupted sleep from gale-force winds and late-night revellers with the Crua Tri. It is made from a patented insulation material that dramatically slashes noise and light levels, while keeping the interior at a comfortable temperature. It sleeps up to three people, and is wheelchair accessible to boot. Nature, here we come!

£587, cruaoutdoors.com

ALPKIT DIRTBAG ↑

A decent camping mat is essential if you want to get a good night's sleep under the stars, and you could do a lot worse than this one. Simply spread it out on the floor and wait for it to puff up all by itself. When you're done, the whole things packs into a stuff sack about the size of a roll of kitchen paper.

£55, alpkit.com

BUNDLE BEDS ↓

Perfect for those who can't bear sleeping bags, the Bundle Bed features a self-inflating mattress, pillow, duvet and sheet, all wrapped up in a handy roll. The bedding is made from moisture-wicking material, to reduce the nasty clamminess that can come with sleeping in a tent, while the 15-tog duvet will keep even the chilliest of campers cosy all night long. Sleep tight.

£199.99, bundlebeds.com

BIG AGNES SENTINEL 30 →

Ideal for couples, the Sentinel sleeps two people. It uses a unique system that lets you slot an inflatable mat into the underside, holding it in place and providing extra insulation. With a soft shell and zips at either side, it feels more like the duvet on your bed at home than a sleeping bag. Plus, the water-repellent down filling will keep you snug when the temperatures plunge below freezing.

$369.95 (£290 approx), bigagnes.com

GADGETS

NOKIA 3310

Though this may fill you with a sense of nostalgia, we chose this phone because it's built for purpose. With little in the way of frills, other than Snake, the phone will last you up to a month on standby. We used it over a weekend in London and only saw the battery drop by 40 per cent. There's a camera for selfies, and if it's anything like it's predecessor it'll put up with a fair few knocks too.

£50, nokia.com

BIOLITE BASELANTERN

Every bit of tech seems to have an app these days and this lantern is no different. Hook it up to your phone via Bluetooth and control the powerful light's brightness and colour remotely. It features two USB charging ports for when your phone is out of juice, and turns on automatically when you approach it – a welcome feature when you are staggering back from the local hostelry in the dead of night.

£126, bioliteenergy.com

BELKIN 6600

This power bank will charge your smartphone three times over – exactly enough to get you through a festival weekend. It's pocket-sized and has two USB slots – so if you're getting into the festival spirit you can help out a friend in need.

£39.99, belkin.com

THEME PARKS

The new attraction at Disneyworld takes visitors into the heart of Pandora

DISNEY RECREATES PANDORA IN FLORIDA

Many readers will, we're sure, have loved the James Cameron movie *Avatar*. In which case, the latest attraction at Disneyworld, Florida might be of interest. Far from just plastering *Avatar* branding on a generic rollercoaster, Disney has pulled out all the stops with this one.

Pandora – The World Of Avatar isn't a ride, but rather a whole new zone inside The Magic Kingdom, in which the fictitious planet's environment has been recreated in impressive detail. And yes, that includes the floating mountains! The latter form the centrepiece of The Valley Of Mo'Ar, a giant film set that you can wander around at will. There's also a family-oriented boat ride down a Pandoran river at night, complete with exotic fauna and bioluminescent flora. What we're most excited about, though, is Flight Of Passage, an IMAX-style cinema experience that puts you on the back of one of the film's mountain banshees, giving you a hyper-realistic, first-person view as you soar around the forests and mountains.

Just don't expect to bump into Jake Sully or Quaritch on your travels. The entire park is set 100 years *after* the Na'vi repelled attempted colonisation by Earth's Resources Development Association, and the whole thing has a strong pro-conservation message.

PHOTOS: DISNEY, BOEING, GETTY

Artist's impression of the spaceplane preparing for launch

SPACE

BOEING AND DARPA BUILD A NEW SPACEPLANE

US military research agency DARPA has announced that it will partner with Boeing to develop its next-generation hypersonic spaceplane, the XS-1.

DARPA has been working on the Experimental Spaceplane XS-1 for several years. The goal is to create an unmanned, reusable craft that can launch payloads into low-Earth orbit at just a few days' notice, compared to the months of planning needed for a Soyuz or Ares rocket launch.

The XS-1 will take off vertically, powered by liquid oxygen and liquid hydrogen propellants. Once the craft achieves sub-orbital altitudes, a booster rocket will launch an expendable upper stage carrying a payload of up to 1,360kg into low-Earth orbit, while the reusable first stage returns to Earth, where it will land on a runway. The craft's primary propulsion system, an Aerojet Rocketdyne AR-22 engine, is derived from the main engine that was used on the Space Shuttle but with lighter fuel tanks. It's hoped that the cost per launch could be as little as $5m, which is far cheaper than the cost of launching a satellite onboard a non-reusable rocket.

In a statement, DARPA spokesperson Jess Sponable said: "The XS-1 would be neither a traditional airplane nor a conventional launch vehicle but a combination of the two, with the goal of lowering launch costs by a factor of 10 and replacing today's frustratingly long wait time with launch on-demand."

TECH BYTES

GOODBYE, MP3

Germany's Fraunhofer Institute is no longer licensing the codec behind MPEG-2, Audio Layer 3 – the MP3 format that launched the digital music revolution. New music streaming and download services will have to use newer formats such as AAC.

RUSSIAN ROBOT

British football fans visiting the next World Cup in Russia will be greeted by a robot tour guide that will translate for them, and contact the police if it detects trouble brewing. It's been given the name 'Alan Tim', after Alan Turing and Tim Berners-Lee.

BRITAIN, REJOICE!

British people can now proudly say that the UK is home to the world's largest wind turbines, after Dong Energy switched on 32 new turbines in Liverpool Bay that each stand 195m tall and sport three 80m-long blades.

TECHNOLOGY

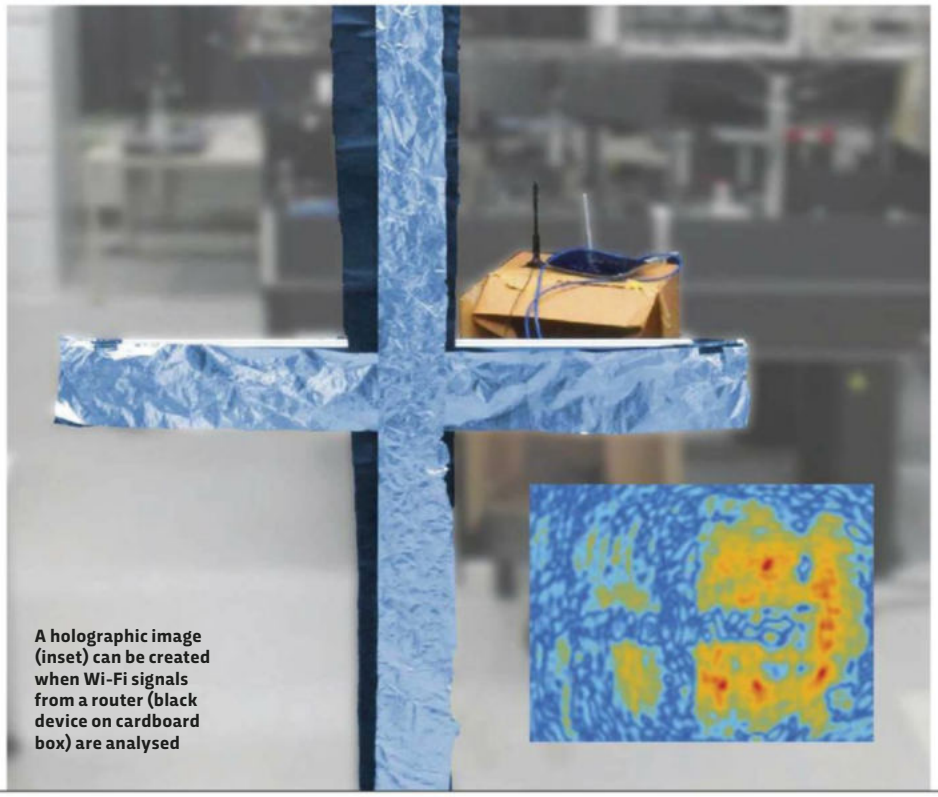
RESCUE TEAMS CAN NOW SEE THROUGH WALLS

Ever wished you had X-ray vision? Researchers at the Technical University of Munich (TUM) have worked out how to create holographic images of the inside of a room or building, simply by scanning Wi-Fi signals outside it.

The technique works by using one fixed and one movable antenna to measure fluctuations in the microwave radiation emitted by devices that transmit a Wi-Fi signal. This information is then converted into a holographic image. The technique isn't new, but previously only worked if large, high-bandwidth transmitters were present. What the Munich researchers have done is fine-tune the technology so that holograms can be created from far weaker signals – such as those used by mobile phones to communicate with Wi-Fi routers.

The most obvious application of the technology is as an aid to rescue workers, who might use it to, for instance, work out the best route through a collapsed building to reach survivors. But it may also have uses in tracking the whereabouts of particular robots or materials in the hyper-automated factories of the future.

As for privacy concerns, the TUM's Friedemann Reinhard, who led the research, says: "It's unlikely that this process will be used for a view into [strangers'] bedrooms. For that, you would need to go around the building with a large antenna, which would hardly go unnoticed."



A holographic image (inset) can be created when Wi-Fi signals from a router (black device on cardboard box) are analysed

TRANSPORT

GO, GO GOGORO!

The Gogoro electric scooter 'sharing' (read: hire) system continues to go from strength to strength, with the launch of two new models and the addition of Paris to the list of cities where Gogoro operates.

The new Gogoro 2 and Gogoro 2 Plus scooters feature an improved electric motor that delivers the same 6.4kW of power but with smoother torque. They also have slightly larger wheels than the original model, plus a longer wheelbase and, accordingly, a longer seat that means riders can carry a passenger in greater comfort.

Meanwhile, in Paris, Bosch's Coup Mobility service will have 600 Gogoros available for short-term rental starting this summer. Coup Mobility already runs a fleet of 1,000 Gogoros in Berlin, after launching the service with 200 of the vehicles only a year ago.

THE OLD OPERATING THEATRE
MUSEUM & HERB GARRET

A medical museum located in the attic of an early 18th century church, once a part of the old St Thomas' Hospital.

It contains the oldest surviving surgical theatre in Europe, pre-dating the arrival of anaesthetics and antiseptics, and the original Herb Garret which once served as a space to dry herbs for the patients' medicines.

This atmospheric museum holds a fascinating collection of historical medial artefacts and offers a unique insight into the history of medicine and surgery in the remains of one of London's oldest hospitals.
Weekly talks available.

www.oldoperatingtheatre.com
Open every day from 10.30 am – 5:00 pm / Admission charge

THE MISSING PASSENGER

FREE ENTRY

The Missing Passenger is a new exhibition trail at the National Railway Museum in York by artist and director Geraldine Pilgrim. Commissioned as part of the museum's new Mystery on the Rails season, *The Missing Passenger* is just one of many activities celebrating the special place railways have in mystery and detective fiction.

The Missing Passenger runs from **23 March** to **3 September 2017**. Entry to the National Railway Museum and *The Missing Passenger* is free.

National Railway Museum

08448 153139
nrm.org.uk/mystery

REPLY

Your opinions on science, technology and *BBC Focus*

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MESSAGE OF THE MONTH

Brushing up

In your article regarding diet drinks in issue 308, you say that research shows that diet drinks are no better than full sugar drinks because they encourage us to eat food as compensation and possibly make less healthy choices.

However my girlfriend and I were wondering what is the best outcome for your teeth. Is it better to go with a diet drink and eat a sugary snack because the sugar does not get into all the cavities as it does with a drink, or to just drink a sugary drink and make sure that you maintain a high standard of dental hygiene?

Brian and Jen, Rochester, via email

That's a tricky one. Sugar-free drinks can still be quite acidic, and therefore are still damaging to your teeth. Research suggests that if you are going to enjoy a soft drink, have it with a meal and use a straw. ***– Ed***

WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* wins a **Ring Video Doorbell and Chime Pro**. The Wi-Fi connected Ring Video Doorbell enables you to see, hear and speak to anyone at your door from a phone, tablet or PC, wherever you are in the UK or abroad. The Chime Pro extends the Wi-Fi signal from your router to your Ring Video Doorbell to ensure you're always connected. **ring.com**

WORTH £208

White with fright

The question about fright turning hair white (June, p80), brought back memories of my great uncle. He was afraid of confined spaces, and many (many) years ago, was trapped in a lift overnight. As a consequence, his hair turned completely white, and remained so for the remainder of his life. I am currently 77 years of age, so you can guess how long ago that experience happened.

Herbert Magri-Overend, via email

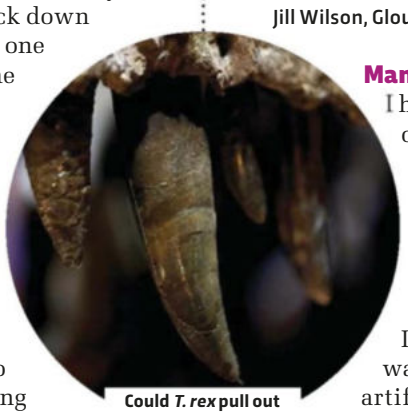
Teething problems

I have been interested in *T. rex*'s forearms and have wondered if he used his 'hands' to tidy up his mouth. I have been assured that he could not reach his mouth with his hands and this looks be the case in all the skeletons and artist's impressions in books and museum displays. But surely he could bend his neck down and round, first to one side and then to the other?

I understand that he had more than one set of teeth. As one was damaged and discarded, another grew and took its place. It is not difficult to imagine him rooting out a broken tooth and so on. It is more difficult to imagine that he had little or no use for his forearms. (This suggestion would be in addition to the activities suggested by Max Jones in his letter in issue 309, of course!)

Jill Wilson, Gloucester

A fright really can turn your hair white, says Herbert Magri-Overend



Could *T. rex* pull out broken teeth?

Man with a plan

I have read a couple of articles by Prof Stephen Hawking where he states humans must leave Earth within 100 years. In another, he warns that artificial intelligence may outgrow our ability to control it because it will redesign itself to perfection. Personally, I don't believe that any human will ever

PHOTOS: SHUTTERSTOCK X2, SCIENCE PHOTO LIBRARY, GETTY

depart this planet after birth.

Today, it is reported that mouse sperm that has visited space has been used to successfully fertilise mouse eggs. I believe that the only way life from Earth can be sent to safety is through artificial intelligence operating the 'ship' and the fertilisation of new life to colonise a new planet out of range of the Sun's expansion. This futuristic Noah's Ark will be more likely than any effort to transport fully formed life to the same destination. (It would be impossible to take indigenous wildlife to the new world without using genetic engineering, and that includes us).

Artificial intelligence will be programmed to manage all aspects of the mission and won't be affected by zero gravity or a limited lifespan. Surely, scientists already know this and that could be a reason for sending mouse sperm to space and back?

I think Hawking might want to consider his current view of artificial intelligence and help design the systems that will save life on Earth.

John Pawson, via email

John Pawson thinks that AI could help us to get off this planet

Considering the contribution AI can make to the world – in terms of science, health and industry – it's almost unethical not to pursue it. I think Prof Stephen Hawking's views on the matter are simply a warning, to encourage governments and labs to approach building AI with proper scrutiny. ***– Ed***

JOIN US ON TWITTER... **@sciencefocus**

@Tom'sNature A well balanced and thought out article by @Josh_Gabbatiss in @sciencefocus this month about the environment and our eating habits #respect

@ChrisDamanaki If a robot starts to hit a car to produce a sculpture is it an artist? If a military drone dances in the sky is it an artist?

@MeganShersby Day 6: Reading the thought-provoking feature by @Josh_Gabbatiss in the July issue of @sciencefocus during my lunch break. #30DaysWild

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CONTRIBUTORS
Peter Bentley, Dan Bright, Jamie Carter, JV Chamary, Alexandra Cheung, Charlotte Corney, Helen Czerski, Emma Davies, David Despau, Dan Falk, Stuart Farrimond, Emily-Jane Gallimore, Alice Gregory, Alastair Gunn, Chris Hall, Tom Ireland, Christian Jarrett, Raja Lockey, Mark Lorch, Magic Torch, Dann Mitchell, James Olstein, Paul Parsons, Helen Pilcher, Aarathi Prasad, Dean Purnell, Govert Schilling, Kyle Smart, Luis Villazon.

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MOBILE
Product and development director Richard Fennell
Head of apps and digital edition marketing Mark Summerton

INSERTS
Laurence Robertson 00353 876 902208

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HACKERS

CAN THEY BE BEATEN?

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horizon

The rise of the internet has transformed hacking into an opportunity for crime, activism and political interference. So who are the hackers and can they be stopped?

WORDS: CHRIS HALL

PHOTO: GETTY

The last six months have been busy for European politics, with Austria, the Netherlands, France and the UK all heading to the polls. Each one of these elections was preceded by fears that hostile powers, acting online, would seek to manipulate the outcome of the elections. These fears came closest to being realised in France, where eventual winner Emmanuel Macron and his En Marche! party were victim to a 9GB leak of emails, just 48 hours before the voting took place. Things are little different across the Atlantic, with four legislative committees, as well as the FBI, investigating alleged Russian influence over the US election, including the hacking of Hillary Clinton's emails. Here in the UK, hacking was recently in the news when the WannaCry ransomware worm crippled computer systems in 40 NHS hospitals in May. In the wake of each attack, politicians spoke urgently of a need to 'regulate' the internet. Across the West, our democracy and our freedom are under sustained attack, and at the heart of the battle is our grasp on technology.

Maybe that sounds like hyperbole, or even the stuff of a movie trailer. Well, consider this: the average person in the UK spends 25 hours a week online and has between 27 and 40 online accounts. There are set to be 8.4 billion connected devices in the world by the end of this year – 20 billion by 2020 – and last year in the US alone there were more than 1,000 recorded data breaches. Hacking isn't just about pinching ▶

passwords any more: the geeks have truly inherited the Earth.

"There's no question that there is more malware now than there has ever been," says David Emms, principal security researcher at antivirus and internet security specialists Kaspersky Labs. "And the volume is growing massively. We analyse a million objects [of malicious code] per day in our virus lab, and more than 60 per cent of our detections are of code that has never seen before."

CYBER CRIME

Such a proliferation of threats is undeniably concerning, but also hard to grasp. One reason the subject of hacking can feel so nebulous is that the term covers a multitude of sins. Cybercrime attacks can be serious offences such as theft, extortion, espionage, libel or fraud, but they can also be low-level nuisance behaviour. Where this comparison with real-world crime differs is that every hack and every leak can feed into greater crimes. For example, stolen user data can be bundled up and traded on the dark web (the dark web refers to encrypted sites that cannot be found using standard browsers or search engines), while compromised machines join sprawling botnets to be unwittingly used in bringing down large targets.

Let's take a look at the NHS ransomare attack as an example. It was carried out using tools leaked online by nefarious group the Shadow Brokers. The tools were recognised by the international security community as hailing from the NSA's Equation Group cyberwarfare team. They contained a number of 'zero-day exploits', which could be used to gain access to computers running Microsoft operating systems from Windows 2000 to Windows 8. The toolkit – known as Eternal Blue – exposed a multitude of vulnerabilities and made it child's play for the perpetrators to spread the WannaCry ransomware around the world.

Hackers targeted Emmanuel Macron just 48 hours before French voters were due to go to the polls – he still beat his rival Marine Le Pen to become president of France

"Stolen user data is bundled up and traded on the dark web, while compromised machines join sprawling botnets to be unwittingly used in bringing down large targets"

/TYPES OF HACK

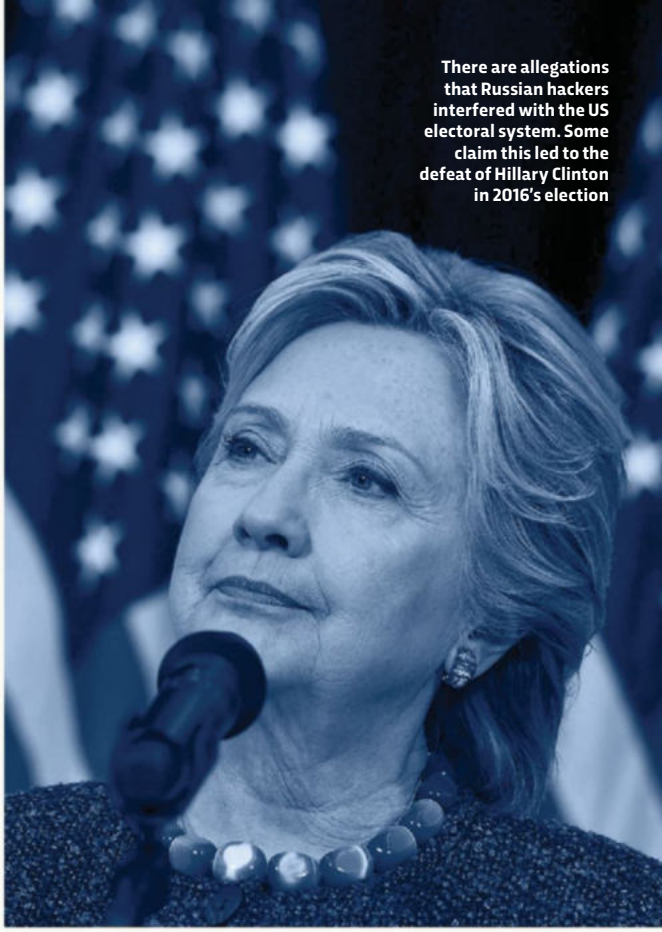
Don't know your Trojan from your worm? Brush up on your hacker lingo here

VIRUSES AND WORMS

Most malware tends to be either a virus or a worm. The difference comes down to the software's ability to propagate. Like their biological namesakes, computer viruses require a host body, whereas worms can spread from one machine to the next unaided.

DDOS

Short for distributed denial of service, a DDOS attack is basic yet effective. It works on the principle that if a website's DNS server can be overwhelmed by traffic requests, the site will crash. Hackers run botnets – networks of zombie computers or devices – to besiege a server from multiple fronts simultaneously.



There are allegations that Russian hackers interfered with the US electoral system. Some claim this led to the defeat of Hillary Clinton in 2016's election

PHOTOS: GETTY X2

Where it gets murkier is when you start to consider the motive for the WannaCry attack. It would seem to be financial, yet relatively little cash was paid out – just $126,000 worldwide (this was easy to track, thanks to the open nature of the Bitcoin transactions that were used for payments). And the attack was relatively easily halted by a security researcher who inadvertently realised that by registering a domain name found within the malware, he activated a built-in 'kill switch'. This doesn't tally with the sophistication of the tools that were used in the attack, or the capabilities of those alleged to be behind it (some have pointed the finger at North Korea).

So how did we get to a point where hackers can rob and extort with impunity, and – if analysis ▶

TROJAN

As its name suggests, a Trojan is a form of malware that sneaks into your computer under an innocuous guise (like an email attachment). Its cargo can be any form of malware. A Trojan's specific ability is getting in, then leaving a backdoor open for others to follow undetected.

RANSOMWARE

This subset of malware made the headlines for the WannaCry attack, but has been around since at least 2012. It searches for important files, encrypts them and demands a ransom (usually paid in Bitcoin) for their safe return. In some cases, the ransomware can lock down a machine rather than specific files.

SPEAR-PHISHING

An evolution of phishing (the spelling harks right back to early phone-based hacking, or 'phreaking'), spear-phishing is more direct, and consists of targeted campaigns, usually over email, to spread malware in a particular network or company. The messages sent out would be laden with Trojans.

/THE BIGGEST HACKS IN RECENT MEMORY

MACRON EMAIL LEAK

Just 48 hours before the run-off poll between Emmanuel Macron and Marine Le Pen, a 9GB cache of emails from Macron's En Marche! party was posted on PasteBin, a filesharing platform. They were spread to WikiLeaks. "The attacks were so simple and generic that it could have been practically anyone," France's cybersecurity chief said.

BANGLADESH BANK HEIST

In February 2016, hackers got the login credentials used by Bangladesh Central Bank for the international banking transfer system SWIFT. They tried to transfer $951m to accounts in Sri Lanka and the Philippines. Most transactions were flagged, but $101m was removed. A Trojan known as Dridex was used, which hides in MS Word or Excel attachments.

WANNACRY ATTACK

On 12 May 2017, a global ransomware attack affected more than 230,000 computers, including PCs in the NHS, FedEx and Deutsche Bahn. The malware was leaked from the NSA, and targeted machines running Windows XP and Windows 2003. The attack yielded just over $126,000 in payments and caused considerable upheaval.

YAHOO! BREACH

In 2016, Yahoo! was forced to confirm that its systems had been breached twice, in 2013 and 2014, resulting in the loss of more than a billion users' personal information, including passwords. The hackers used fake browser cookies that allowed them to dupe the site's login systems. To date, it is the largest loss of customer data by any single company.

CHIPOTLE ATTACK

The Mexican restaurant chain, which has more than 2,250 outlets in the USA, reported that if you paid with a credit card between 24 March and 17 April 2017, your credit card details had almost certainly been obtained by hackers. The attack vector has not been confirmed, but the malware involved allegedly read the card data directly from the machines as they took payment.

is to be believed – nations such as Russia or North Korea can interfere in political campaigns? Russian president Vladimir Putin came close to conceding that Russian elements could be behind recent political hacks. "If hackers are patriotically minded, they start to make their own contribution to what they believe is the good fight against those who speak badly about Russia," he said in a recent interview. (Those with longer memories will point out that interfering in the elections of satellite states was a favourite activity of the US during the 1980s – it just wasn't done online.)

One side of the answer is the exposure of people to the internet. As the Internet of Things grows, we are adding 'attack vectors' to our lives. We are opening more and more doors for hackers to walk through. "Smart home technology has not yet been universally adopted, so attackers don't have much to gain from it other than nuisance value," explains Emms. But that may soon change when smart home technology reaches a tipping point, and the weaknesses are there to be exploited.

"Companies who have never had to think about internet security in the context of standalone products wake up to the need for security when

PHOTOS: GETTY X3, ALAMY X2, SHUTTERSTOCK

they add Internet of Things functionality," says David Harley, a security consultant and chief operations officer for the Anti-Virus Information Exchange Network. Although, he adds, the smart home's sheer scale could also act in its favour.

"Because of the wide diversification of brands, technologies and devices, the scope of an individual attack may be comparatively restricted." Restricted or not, there is the potential for some creatively unpleasant hacking. "Imagine a ransomware attack linked to your heating system!" says Emms.

So, you don't have to worry about someone hacking into your smart kettle – yet. But that's only because there are easier ways for criminals to get what they want, whether that's by simply buying leaked data, sending out a few thousand phishing emails, or exploiting existing vulnerabilities that go unfixed by users who neglect to update their software.

BLAME GAME

But we can't place all the blame on lazy individuals or companies. The majority of security researchers concur that without punishment, crime is allowed to flourish.

"It is a myth to think criminals have some magical edge," says Stephen Cobb, senior security researcher at antivirus specialists ESET. "Right now it appears that way with cyber criminals because of the massive failure of governments to mobilise international law enforcement. How many culprits involved in watershed breaches have been brought to justice? Clearly, not enough to deter new entrants to the field."

But who are these hackers anyway? The security community is generally cagey about attributing attacks to certain groups or countries, seeing it as the responsibility of law enforcement to act on their pure analysis of the code. Nonetheless, the anonymity offered by the internet makes it hard to be certain. The few major hacking groups that are known to security researchers are the exception, not the rule, and their actual membership can be even harder to pin down.

> "Back when I started, it really was the Wild West out there. And there was an innocence to it. When groups of us met in chatrooms, we didn't really realise we were creating criminal gangs"

Cal Leeming gained notoriety as the UK's youngest convicted hacker in 2007. According to Leeming, his natural talent was "given a bit too much freedom". He was carrying out illegal attacks at the age of 12, then in 2006 he was sentenced for using stolen credit card data to buy £750,000 worth of goods. Now running his own security consultancy for high net worth individuals, he laughs when asked if hackers really fit people's image of them.

"Stereotypes do generally exist for a reason," he says. Still, he doesn't quite live up to these stereotypes, as his childhood hacking was borne of a need to support his family rather than a desire for mischief. "Back when I started, it really was the Wild West out there. And there was an innocence to it. When groups of us met in chatrooms, we didn't really realise we were creating criminal gangs. I used to think the internet should be totally free, no rules, everything goes," he explains. "But we have got to a point where the internet, and anonymity in particular, has brought out the very worst in our culture. It has brought out the best too, but we have become desensitised to how awfully we're treating each other."

As an emerging hacker, Leeming lacked guidance but also felt that the law was too heavy-handed. "It has criminalised schoolkid mischief," he says. He cites the tendency of small crimes to turn into bigger ones. "We need people who can interact with those kind of young ▶

'Hactivist' group Anonymous tend to attack religious and political groups, and large corporations. Many members opt to wear the stylised Guy Fawkes mask

/THE BIG PLAYERS

Who are the most notorious hacking groups out there and what do they want?

FANCY BEAR

Also known by a myriad of aliases including Sofacy, APT28 and Pawn Storm, this highly capable group is widely believed to operate with at least the tacit approval of the Russian government. It has claimed responsibility for attacks on NATO, the White House, the French election, the DNC and German parliament.

LAZARUS GROUP

This group is known for the attacks on Sony Pictures and the Bangladesh Central Bank in 2014 and 2016, respectively. The Lazarus Group is also thought to have attacked the South Korean government between 2007 and 2013. Specialising in financial attacks and espionage, the group has been linked by researchers and the media to the North Korean regime, albeit not conclusively.

SHADOW BROKERS

One of the newest groups to emerge, Shadow Brokers published leaked hacking tools from the NSA in summer 2016, with the possible assi nce of a former military contractor at Booz Allen Hamilton. Little is known about the group's identity or motives, but there is speculation that the leak's main purpose is to send a message of mutually-assured destruction if the US were to retaliate for the group's hacks on the Democratic National Committee in 2015 and 2016.

UNITED CYBER CALIPHATE

The UCC, also referred to as the Islamic State Hacking Division, refers loosely to all groups claiming to further the ideology of ISIS. Yet it is not known how coordinated it is with others, such as the Tunisian group that claimed responsibility for an attack on the NHS in February. The group has attacked American, British and Australian targets.

EQUATION GROUP

Classed as one of the most advanced threats by security companies, the Equation Group (named for the complexity of its encryption) is commonly believed to be affiliated to the NSA and has been particularly involved in cyber attacks across the Middle East. One such attack was the Stuxnet worm, which destabilised Iranian nuclear centrifuges.

PHOTO: GETTY

adults – people who otherwise develop no grasp of ethics or personal responsibility."

However, the general consensus among experts is that hackers and hacking are something we need to accept will never disappear, yet that doesn't mean we have to give up the fight.

"There will always be some level of criminal hacking, but it is possible to improve human behaviour. For example, there's a lot less crime in America and the UK today than there was 25 years ago, and not because all the criminals have gone online," says Cobb.

When the diagnosis is as all-encompassing as a global issue like cybercrime, so the prescriptions are going to be pretty far-reaching. For David Emms at Kaspersky, it's an education issue.

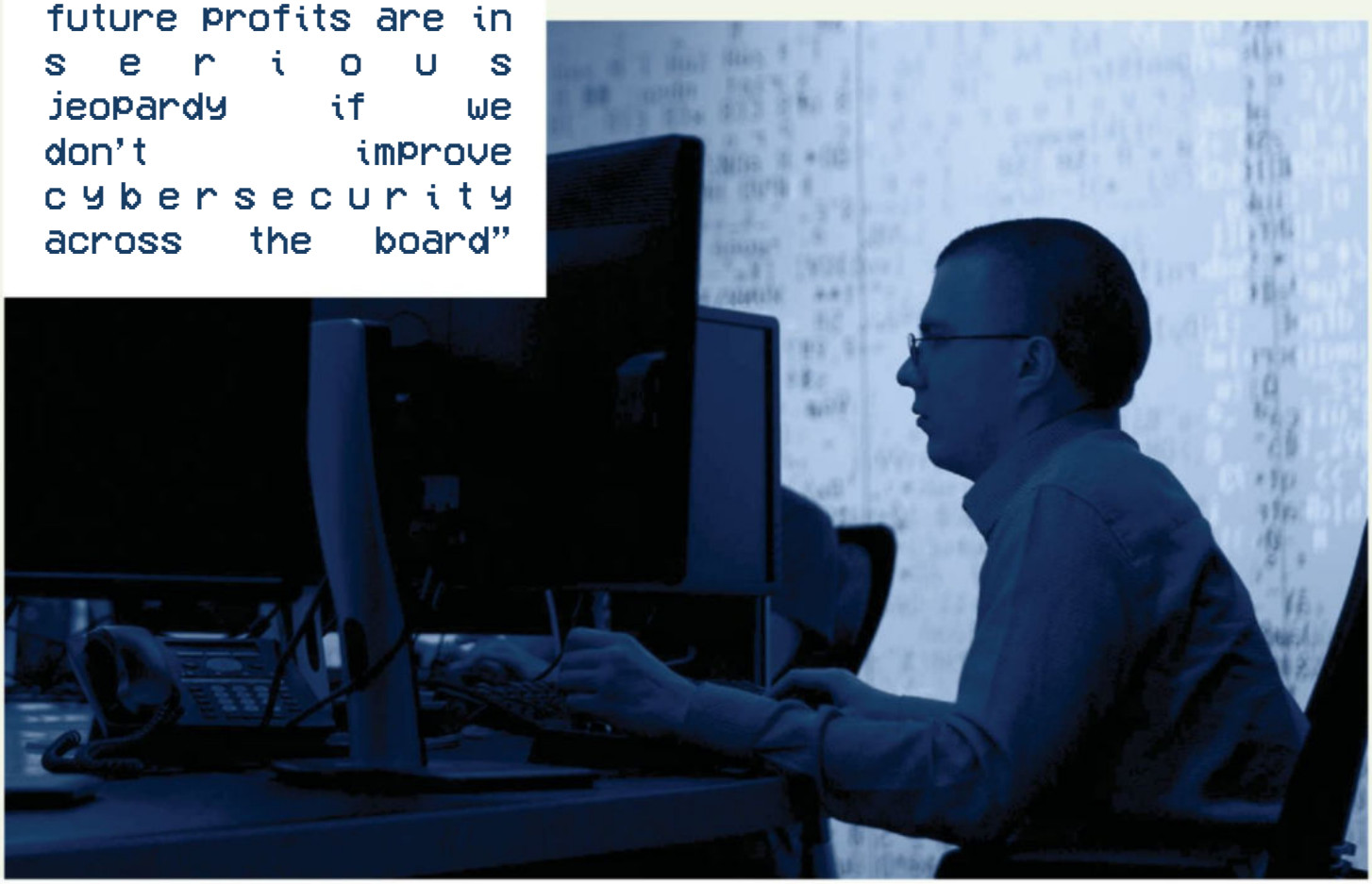
"Cyber attacks are so often reliant on humans and their mistakes, so big businesses could go a long way towards dealing with the problem by focusing more on a culture of awareness and developing education," he says. "It's like parenting, you can't expect to tell your kids to do something once and they'll never do it again. It's a longer-term process."

However, there's no question that serious vulnerabilities remain. "I think the big tech companies need to take a step back and realise that their future profits are in serious jeopardy if we don't improve cybersecurity across the board," says Cobb. "There are massive tech companies sitting on billions in cash and I would argue a chunk of that cash came from the corner-cutting we have done so far."

But that doesn't mean it's all doom and gloom. It's a glorifying myth, says Harley, to think of it as "genius hackers versus plodding security companies". Instead, if we think of hackers like ordinary criminals and guard against them in the same way, then there's no reason why society, including the public, the media, companies and governments, cannot keep cybercrime under control.

Chris Hall is a science and technology journalist who has written for *Esquire*, *Men's Health* and *GQ*.

"The big tech companies need to take a step back and realise that their future profits are in serious jeopardy if we don't improve cybersecurity across the board"



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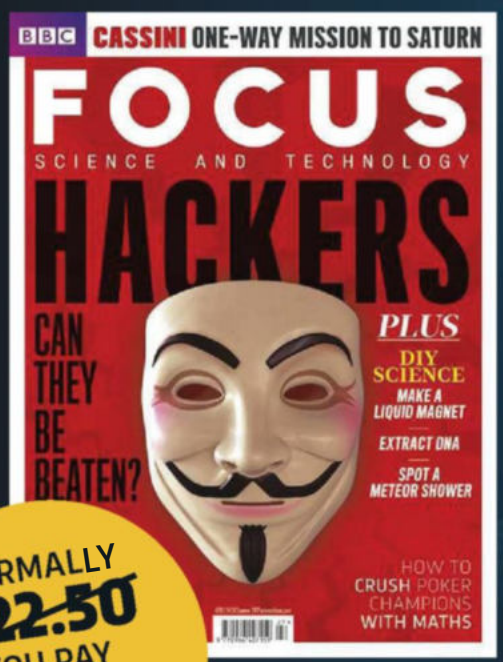

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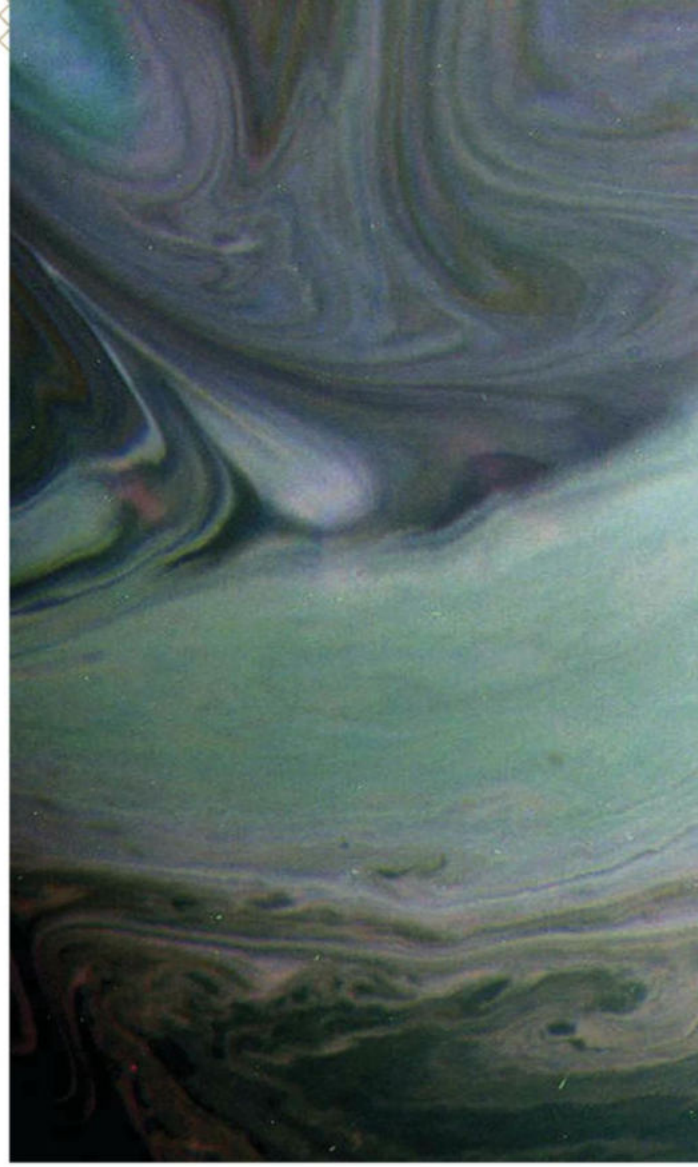
CASSINI'S LAST HURRAH

Later this year, Cassini's two-decade-long mission to chart Saturn and its moons will come to a close. But before the craft ends its trip with a fatal plunge into the gas giant's atmosphere, we thought we'd take a look at some of the incredible discoveries it has made

Words: GOVERT SCHILLING

PHOTO: NASA



It sounds like a scene from the ultimate disaster movie: speeding along at 113,000km/h, a $1.5bn vehicle the size of a bus plummets into a foggy abyss. Within a few brief minutes, it is shattered into pieces by built-up pressure, its delicate parts vaporised by frictional heat. It's a dramatic end to what has been hailed as the most successful exploratory space mission in human history. Surprisingly, the fatal plunge – due to occur on Friday 15 September this year – is no accident. After studying Saturn for more than 13 years, the Cassini spacecraft will be deliberately sent into a trajectory, burning up in the giant gas planet's atmosphere.

MISSION ACCOMPLISHED

"It has been an incredible mission," says project scientist Linda Spilker of NASA's Jet Propulsion Laboratory in Pasadena, California. "Cassini has rewritten the textbooks on Saturn." So why destroy it? The exciting answer: to protect possible microbial life on Saturn's moons. According to Spilker, Cassini's small thrusters have almost run out of fuel, so the craft will be soon be impossible to steer. If the craft is not destroyed, it could crash into the moon Enceladus, contaminating its subsurface ocean – one of the most promising environments in the Solar System for finding extraterrestrial life.

RIGHT: **Planet Earth (indicated by arrow) can be seen peeking out from behind Saturn**

Thanks to its majestic system of rings, Saturn is considered by some to be the Solar System's most beautiful planet. Over 35 years ago, the gaseous giant was briefly glimpsed during fast flybys of three earlier spacecraft – Pioneer 11, Voyager 1 and Voyager 2. But Cassini, launched in October 1997, has a permanent view from its elliptical orbit around Saturn. Ever since its arrival on 1 July 2004, its suite of instruments has studied the planet's atmosphere, ring system and retinue of satellites. Some 130 close encounters with Titan, Saturn's largest moon, were staged in such a way that Titan's gravity deflected the spacecraft towards close encounters with other moons.

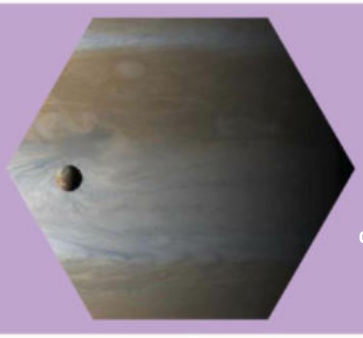
PHOTOS: NASA X6

20 YEARS OF CASSINI

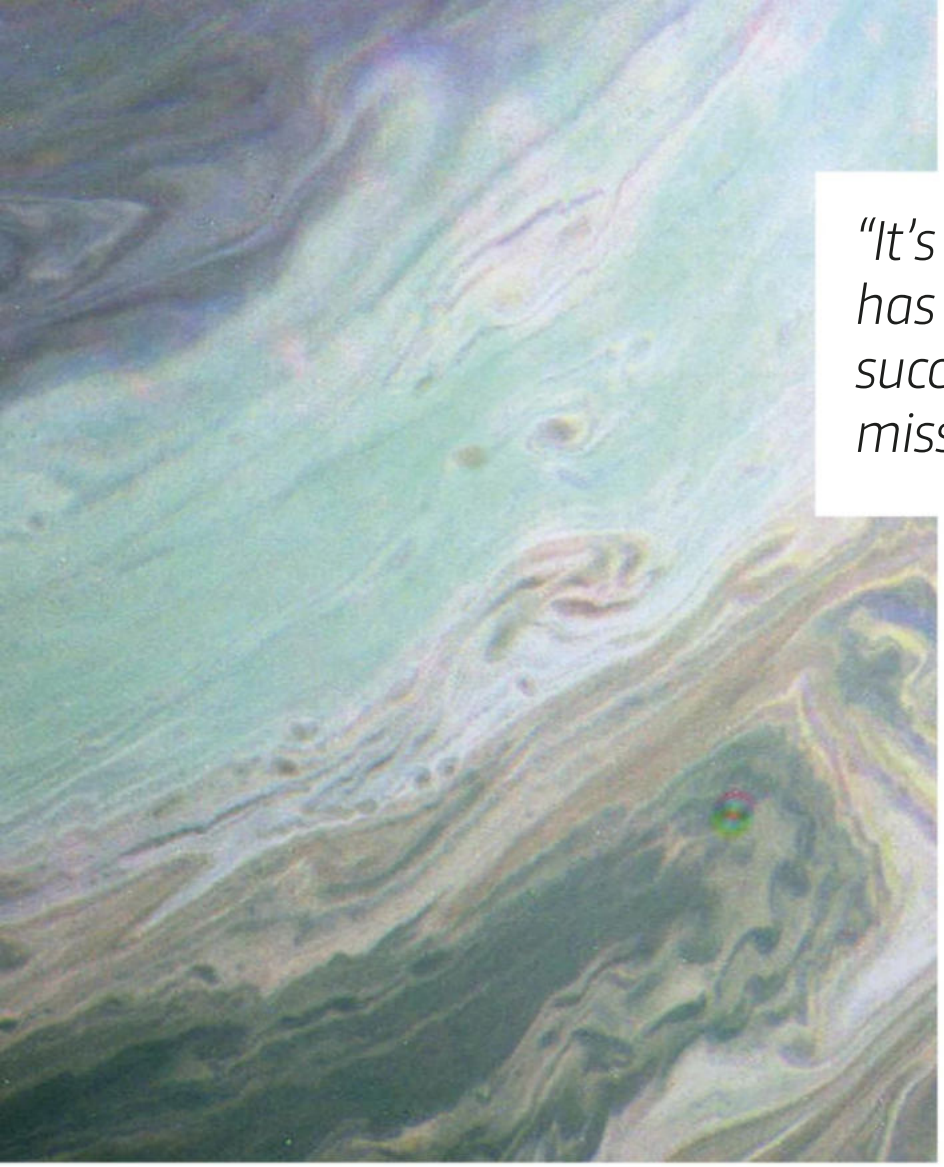
How did the plucky spacecraft's mission pan out?

OCT 1997
Cassini launches from Cape Canaveral aboard a Titan IV rocket

APR 1998
First flyby of Venus, for course correction and acceleration



DEC 2000
Flyby of Jupiter (left), for course correction and acceleration



"It's a dramatic end to what has been hailed as the most successful exploratory space mission in human history"

The most awe-inspiring legacy of the Cassini mission is its collection of almost 400,000 photos. While every picture contains a wealth of scientific information, many of the eye-catching shots – including surrealistic views of the ring system, stark images of light and shadow, and serene shots of multiple moons – were taken at least partly for aesthetic reasons. "My favourite one was taken on 19 July 2013, when the Sun was behind Saturn as seen by Cassini," says Spilker. A minute speck of light in the eerie photo is actually planet Earth. "The remote view of this tiny world helps you to put things in perspective," she adds.

Because of its distance from the Sun and its lower temperature, Saturn's clouds form at a deeper level in the atmosphere than Jupiter's, rendering them less striking. Still, during almost half of Saturn's seasonal cycle, Cassini successfully snapped pictures of wavelike patterns, numerous small eddies, and even a giant storm system at mid-northern latitudes that recurs once every Saturnian year. Atmospheric scientists were stunned by the churning vortices and maelstroms at the planet's poles – persistent cyclones 20 times larger than their terrestrial counterparts – and by the giant hexagonal pattern of standing waves surrounding Saturn's north pole.

ABOVE: **False-colour image of Saturn's northern hemisphere, as photographed by Cassini's wide-angle camera**

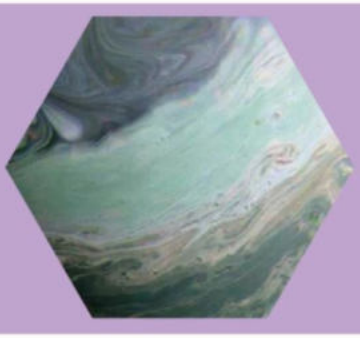
OVER THE MOON

Even more exciting was Cassini's step-by-step exploration of the surface of Titan. The huge moon is covered in smog, but infrared cameras and radar instruments managed to image and map shifting sand dunes, ice volcanoes, mountain ranges and even patchy networks of lakes, filled with liquid hydrocarbons like methane and ethane. The European Huygens probe that hitched a ride to Saturn with Cassini and soft-landed on Titan in January 2005 provided valuable data about the moon's surface. It discovered that Titan is a frigid and swampy environment, rich in organic compounds. It is battered by massive storms of methane rain, and littered with pebbles and boulders of frozen water. In other words, Titan is a science-fiction writer's paradise.

Other moons turned out to be no less bewildering. Take Hyperion, for instance, that's as porous as pumice. Or tiny Pan, orbiting within one of the gaps in Saturn's rings and shaped like ◉

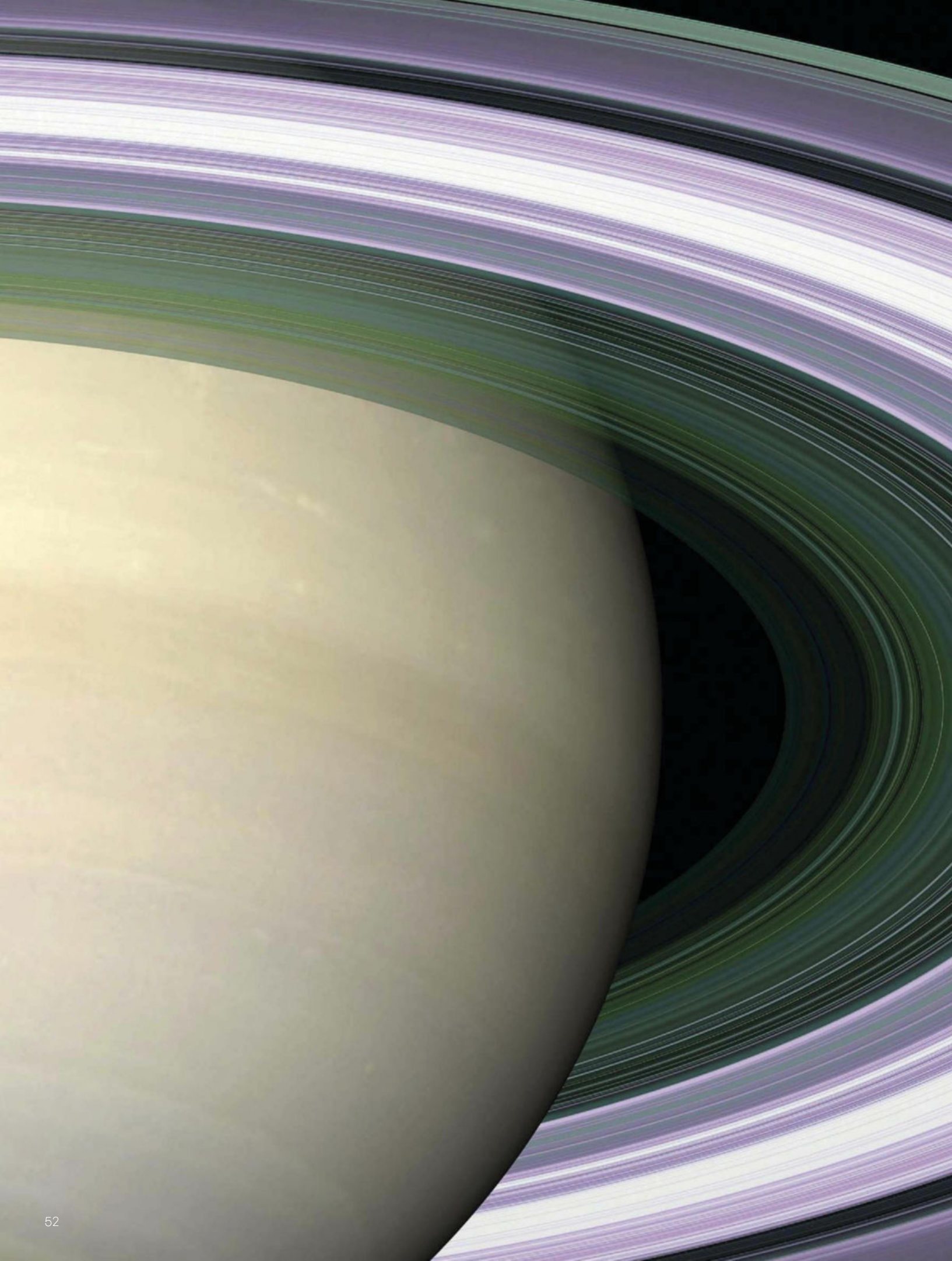
JUN 2004
Flyby of Phoebe (right), one of Saturn's outer moons

JUL 2004
Arrival in orbit around Saturn (right)



OCT 2004
First flyby of Saturn's giant moon Titan

JAN 2005
Landing of European Huygens probe on Titan



NASA used wavelength data taken from Cassini to create this simulated image of Saturn. Colour has been added to show differences in ring particle sizes

CASSINI'S CONTRIBUTION

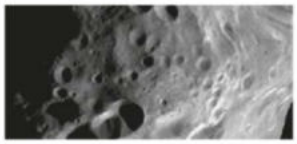
Some of the insights that have been captured by the spacecraft

TITAN FALL

Panoramic picture of the landing zone of the European Huygens probe on Titan, as seen from a 10km altitude. Huygens touched down at the base of a mountain range.

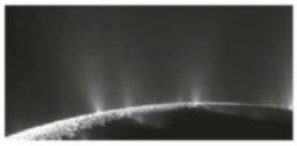
SMOGGY SATELLITE

Photomosaic of Titan, made by Cassini during its flyby on 13 November 2015. The individual photos were shot by the craft's infrared instruments, which enabled a view through the smog layers in the nitrogen-rich atmosphere.



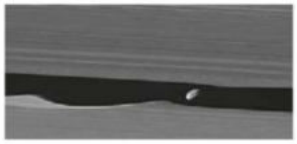
CHILLY MOON

Before entering its orbit around Saturn, Cassini approached the outer Saturnian moon Phoebe to within 12,000km. Phoebe is irregularly shaped and heavily cratered, and measures some 200km across. The moon's low density indicates that ice is a major constituent.



GLOWING GEYSERS

The geysers of Enceladus show up clearly when backlit by the Sun. They were discovered by Cassini in 2005. They indicate the existence of an ocean beneath the frozen surface of the icy moon.

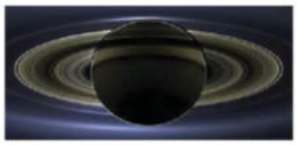


MIND THE GAP

The gravity of Saturn's tiny moon Daphnis, which orbits the planet in the narrow Keeler Gap, produces strange wavelike patterns in the ring system. Daphnis is just 8km across, but continuously sweeps up tiny ring particles.

SHADOWY PLANET

This photomosaic of Saturn shows the unlit side of the ring system. The rings cast their shadow on Saturn's cloud deck, just north of the planet's equator.



ICE RINGS

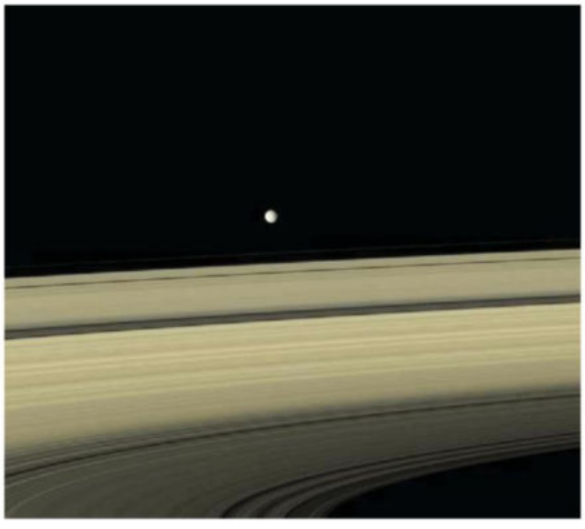
Cassini took this image of Saturn and its ring system while passing through the planet's shadow. The outer purple band is Saturn's very tenuous E-ring, which contains dust particles and ice crystals that originate in the geysers of Enceladus.

a flying saucer. Or Mimas, known as the Death Star moon because of its giant circular impact blemish. And don't forget mysterious Iapetus, the yin-yang moon with one dark and one bright hemisphere, which sports a 20km-high 'mountain range' of collected debris on its equator.

Still, nothing can beat Enceladus. From cracks near the south pole of this small frozen moon (it measures just 500km across), geysers of dust, water vapour and ice crystals spew into space – proof of the existence of a subsurface ocean. Tidal friction from Saturn heats up the interior, producing hydrothermal vents at the ocean floor. On Earth, similar underwater vents teem with weird forms of life that rely on chemicals instead of sunlight. Who knows what organisms might thrive beneath the surface of Enceladus. "The 23 close flybys of this tantalising moon have hugely changed our thoughts about the best way to look for extraterrestrial life," says Spilker.

LORD OF THE RINGS

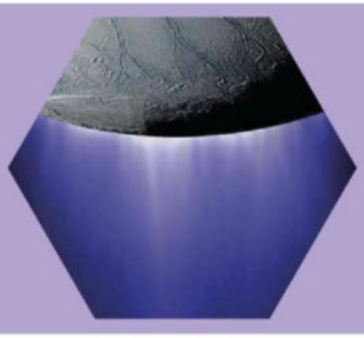
Of course, much of Cassini's time has been devoted to studies of Saturn's iconic ring system. Despite measuring roughly 273,000km across, the average thickness of the rings is just 20m. Gravitational interactions with embedded moonlets produce narrow gaps, tightly-wound spiral waves, propeller-shaped disturbances, clumps and kinks, and even vertical 'walls' of uplifted ring material, casting dramatic shadows during Saturn's equinox. Yet scientists are still



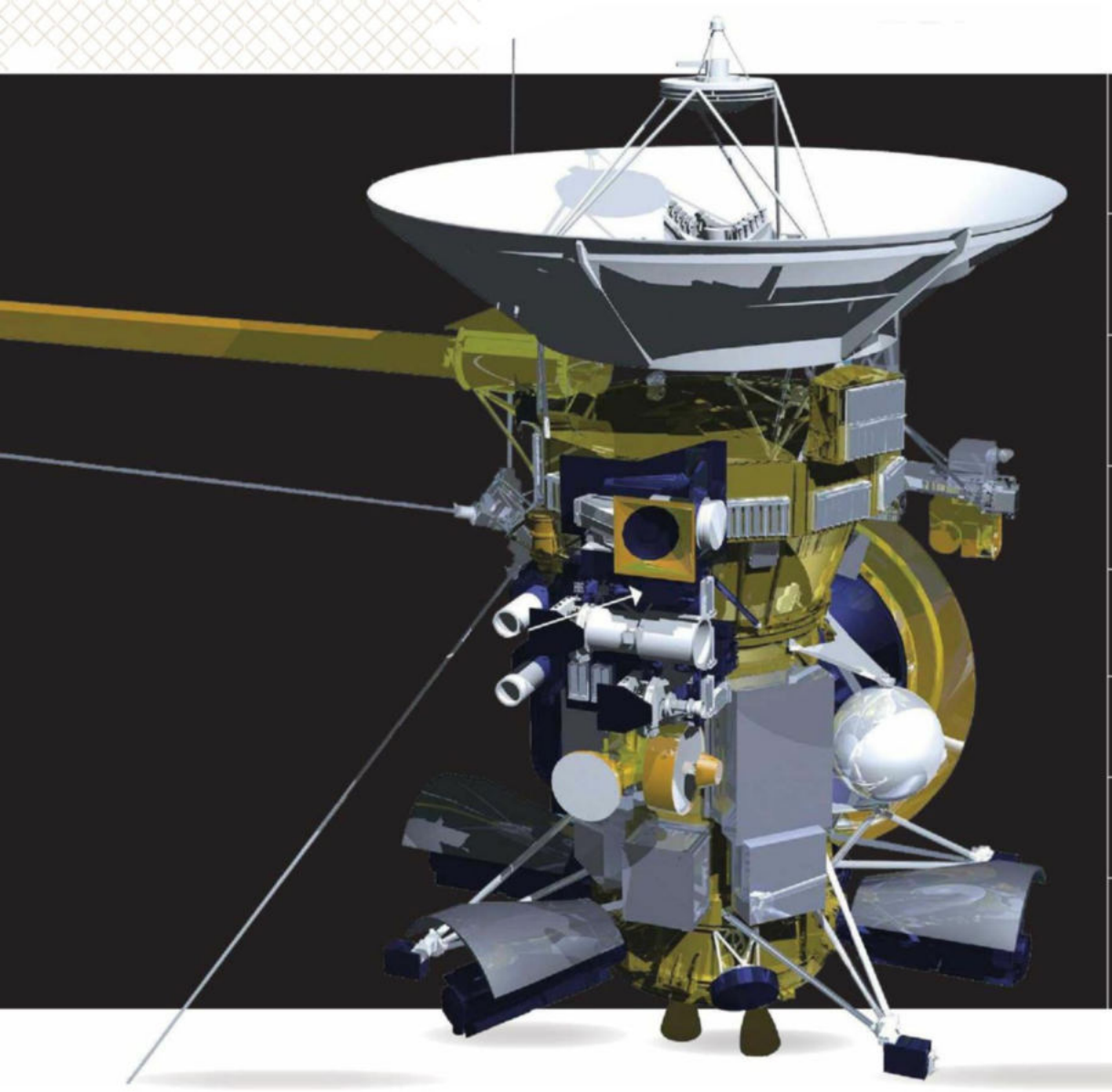
RIGHT: **Saturn's moon Mimas pictured above the planet's rings**

PHOTOS: NASA X13

MAY 2005
Discovery of geysers erupting from the south pole of the moon Enceladus



JULY 2006
Discovery of hydrocarbon lakes on Titan (left)



CASSINI IN NUMBERS

2,150
kilograms in mass

32.7
kilograms of radioactive plutonium fuel on-board

379,300
images taken

3,616
science papers published

243
orbits competed

10
moons discovered

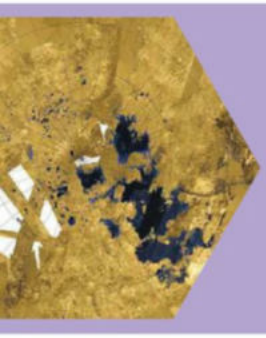
122,900
top speed in km/h

unsure about the age of the ring system: did it form billions of years ago, at the same time as Saturn, or is it the scattered debris of a recently shattered moon?

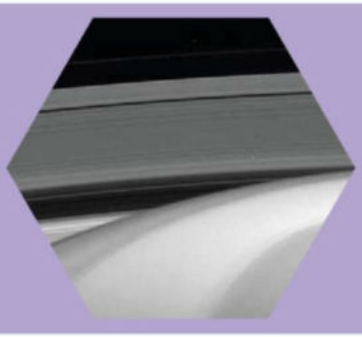
It's one of the puzzles the Cassini team hopes to solve this summer. Since April, the intrepid spacecraft has been performing a series of staggering dives through the 2,000km-wide gap between the planet's cloud tops and the inner edge of the rings. By precisely tracking Cassini's path, it will be possible to 'weigh' the rings for the first time ever. "If they're low-mass, they can't be old, or they would've been eroded away by micrometeoroids long ago," says Spilker. The daredevil dive manoeuvres will also yield the most detailed views of Saturn's atmosphere, its tiny inner moons, and, of course, of the rings themselves.

Speaking about the mission coming to a close, Spilker says: "It's probably going to be a weird mix of happiness and sadness. There will be applause and toasts, but also grief and tears. Maybe the biggest feeling of loss will be about the disbanding of the Cassini team – many of us have devoted a large part of our lives to this mission, and we've become one big family."

Govert Schilling is an astronomy writer based in the Netherlands. His new book, *Ripples In Spacetime*, is out on 31 July (£23.95, Harvard University Press).

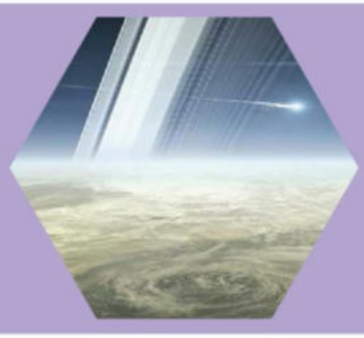


JUL 2013
While at Saturn, takes photographs of Earth (located by arrow, left)



APR 2017
First dive through the gap between Saturn's cloud tops and rings

SEP 2017
Plummets into Saturn's atmosphere, ending its mission



DIY SCIENCE

The long summer days bring sunshine, sand, sea and… science? Here are some entertaining and eye-opening experiments to try at home with family and friends. No specialist equipment is needed, and sunnies are optional. Just remember to wash hands after carrying out the activities and make sure that children are supervised by an adult

WORDS: DR STUART FARRIMOND
PHOTOGRAPHY: STEVE SAYERS/THE SECRET STUDIO

FOR MORE DIY EXPERIMENTS TO TRY AT HOME, VISIT THE BBC'S TERRIFIC SCIENTIFIC SITE **BBC.CO.UK/TERRIFICSCIENTIFIC**

SAFETY NOTES

Do not drink ferrofluid.

Rare earth magnets are powerful! Do not swallow. Do not allow young children to play with them.

Ferrofluid will stain, so protect skin and surfaces.

YOU WILL NEED:

- *Ferrofluid (we bought ours from first4magnets.com)*
- *Rare earth magnet (these are extremely strong magnets, usually made out of neodymium)*
- *Paper towels and cleaning materials*
- *Gloves*
- *A plate, or a large, washable table surface*

FUTURISTIC FERROFLUID

METHOD:

1. Wearing your gloves, pour a little of the ferrofluid onto a plate or wipeable table surface (avoid woods that might stain).

2. Place the rare earth magnet underneath the plate or table and watch the black liquid spring into life. Hedgehog-like spiky tufts will form directly above the magnet, following its movements as you slide it around the underside.

3. Blow on it to watch the spikes spin! You can even make the ferrofluid crawl up surfaces and – if you don't mind making a mess – hover the magnet over the surface to see it defy gravity by 'dripping' upwards onto the magnet, transforming it into an eerily squidgy, slimy black ball.

WHAT'S GOING ON?

A ferrofluid is an oily liquid blended with microscopic particles of metal. It is combined with a liquid 'surfactant' to prevent clumping. It forms such crazy shapes in the presence of a magnet because the metal particles try to align themselves along the path of the magnetic field.

You can buy small bottles of ferrofluid online for a few pounds, or you can try making your own by mixing a cupful of laser printer toner with a little cooking oil. Be aware that not all modern laser printer ink is magnetic, so only try it if you have some spare. Like black printer ink, all ferrofluids stain easily, so make sure that you wear gloves and be careful where you pour it. You may want to consider putting on an apron.

EXTRACT DNA IN YOUR KITCHEN

SAFETY NOTES

Wear safety glasses when using methylated spirit.

Do not drink methylated spirit.

Keep fingers away from sharp blades on kitchen equipment.

Wash hands after touching plants, soil or animals.

Do not allow children to visit a beach unsupervised.

YOU WILL NEED:

- *Safety glasses*
- *A small handful of strawberries (broccoli, peeled kiwi fruit, spinach or split peas will also work well)*
- *Food blender*
- *Sieve*
- *Bowl*
- *Tall glass or test tube*
- *Salt*
- *Washing-up liquid*
- *Pineapple juice*
- *Methylated spirit (meths)*
- *Ice or a freezer*
- *Toothpick, tweezers or small skewer*
- *A large pipette or turkey baster*

TV cop shows have made DNA extraction glamorous – with just a tuft of hair or speck of blood, crime scene investigators can isolate the genetic fingerprint of the 'perp' and bring them to justice. So you may be surprised to learn that DNA can be extracted from organic material in the kitchen, with just a few household ingredients.

WHAT'S GOING ON?

The washing-up liquid opens the fat-like membrane that makes up the walls of each strawberry cell's nucleus, inside which the DNA is stored. The DNA is tightly coiled around specialised nuggets of packaging proteins, which need to be broken up before they can be extracted, and the pineapple juice contains a protein-digesting enzyme called bromelain which does this. Every DNA molecule is extremely long and is peppered with tiny positive and negative electrical charges, each of which is hugged by opposing tiny charges of the surrounding water molecules. The sodium and chlorine from the salt form a coat around the DNA, helping it clump together when mixed with alcohol.

The methylated spirit causes DNA molecules to separate from the mixture and 'precipitate' out as a solid mass. DNA is delicate, so the meths needs to be poured in carefully without stirring.

METHOD:

1. Put a handful of strawberries in a blender with half a cup of water and a pinch of salt. Blitz for at least 30 seconds until it achieves a smooth consistency.

2. Separate the tough, fibrous material by pouring the mixture through a fine sieve. Use the back of a spoon to squeeze all the juice through, leaving the cellulose behind.

3. Add a good squirt of washing-up liquid (about 30ml). Stir it and leave it for 5-10 minutes. Add a splash of pineapple juice.

4. Decant the (now undrinkable) strawberry juice into a tall glass or test tube. We did this with a turkey baster to avoid splashes.

5. Put on your safety glasses, and use a turkey baster to draw some ice-cold methylated spirits out of the bottle and trickle it down the side of the glass.

6. The meths will float on the surface. At the boundary of the two liquids, wispy threads will materialise. This is the strawberry's DNA and can be plucked out (see right).

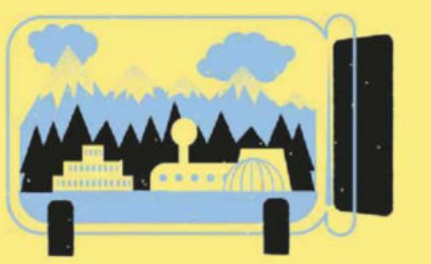
FUN FOR NATURE LOVERS

SEARCH FOR SEAWEED FOR SCIENCE!

A trip to the coast will feature in many people's summer plans, and presents an ideal opportunity to take part in the Big Seaweed Search, which is being run by the Natural History Museum in collaboration with the Marine Conservation Society.

Seaweed plays a vital role in creating underwater habitats and providing food for fish and other marine creatures. We don't yet fully understand what impact climate change is having on seaweed species, but armed with nothing more than a pen, some paper and a smartphone or camera, you can help scientists get to grips with what is happening.

Visit nhm.ac.uk/seaweeds to download a seaweed guide and recording form, then start rockpooling! Submit your observations and photos online.



CREATE A WORLD IN A JAR

This summer, why not make a self-contained ecosystem? Called a 'terrarium', your small biosphere will house plant life that can survive without human intervention for years – perhaps even decades!

Pour a 2-3cm layer of gravel or pebbles into a jar. This will allow a space for moisture to drain. Add a thin layer of activated charcoal, which is available from pet shops – this will help to remove impurities from the water. Add a 2cm layer of good potting soil.

Next, choose a plant that grows well in humid conditions, such as a strawberry begonia, spiderwort or fern. Trim back the roots so it doesn't grow too large, plant it in the soil and add some sphagnum moss around the edge. Spray in a little water to moisten the leaves, then seal the jar and place it in a bright, indoor spot, near a window and away from radiators.

You may need to open the jar once a week to give it a clean if there is a lot of condensation; other than that, your newly built ecosystem should look after itself.

SOFT DRINKS VS YOUR TEETH

YOU WILL NEED:

- *Eggs*
- *Selection of soft drinks (we used orange juice, fizzy water, cola and an energy drink)*
- *Tap water (this acts as a control, for comparison)*
- *Enough glasses or mugs for each drink*
- *Sticky labels*
- *A toothbrush*

We often hear about the dangers of sugary soft drinks, but this eye-opening experiment shows you that all acidic drinks can be bad for your pearly whites – even the ones you thought were healthy…

WHAT'S GOING ON?

Egg shells are made of calcium carbonate – a hard mineral that is similar to calcium phosphate, the substance our teeth are made of. Acids react with calcium carbonate, breaking it apart into calcium (which is carried off in the water) and carbon dioxide gas. The more acidic a liquid is, the faster the reaction and the more the shell will weaken. The bubbles and froth that form on the egg and on the surface of the liquid are carbon dioxide gas, showing that the mineral is quite literally 'fizzing' away in the tart-tasting liquid.

The results may shock you: orange juice, which is typically seen as a 'healthy' drink, is naturally high in citric acid and causes more dramatic changes than cola. Fizzy water is also acidic because it contains dissolved carbon dioxide, which forms carbonic acid. Commercial soft drinks are remarkably corrosive because manufacturers add extra acids to give them a 'tang'. But it's energy drinks that are consistently among the worst offenders, typically being as acidic as vinegar.

METHOD:

1. Collect a selection of soft drinks.

2. Pour enough of each drink into separate glass to completely cover the egg. Don't forget to include one with tap water.

3. Label each glass and leave overnight. Leave for a week to witness even more dramatic results!

4. Carefully remove each egg to examine the shell.

5. Rub gently with a toothbrush to simulate the effect of brushing your teeth after exposure to the acidic drinks (see main image).

FUN FOR STARGAZERS

WATCH NATURE'S FIREWORK DISPLAY

The streaks of light we call 'shooting stars' are really meteors: tiny fragments of stone or ice that plough into Earth's atmosphere at around 160,000km/h and burn up on entry. On any clear, dark night you might spot the odd meteor but at certain times of year they appear in a dramatic flurry. From 27-30 July, the Delta Aquariid meteor shower will reach its peak, resulting in up to 20 meteors per hour, and on 11-12 August it's the turn of the famous Perseids, when you might see up to 90 per hour.

You don't need any special equipment for meteor spotting: just wear warm clothes and head somewhere very dark, well away from city lights. A sunlounger will, however, make for more comfy viewing!

BUILD A SUNDIAL

The simplest sundial needs nothing more than a waterproof paper plate, a straw, and a permanent marker. Poke a small hole in the middle of the upturned plate and fix it on the ground or a table outside. Poke the straw through the hole and, at midday, write '12' on the edge of the plate in line with the straw's shadow. Then mark the position of the shadow every hour, and continue the next day until you have all the daylight hours recorded. You now have a reliable 'clock' that will serve you the whole summer – no charging needed!

The adventurous can build a more permanent sundial with wood and nails. Printable sundial templates are also available at **go.nasa.gov/2tgh33Y**

CHART THE GALAXIES AT HOME

With opportunities for stargazing limited on short summer nights, many enthusiasts turn to citizen science astronomy projects. From your home computer you can join thousands of other amateurs in helping scientists make sense of the endless stream of data and imagery from space telescopes like Hubble and Kepler and ground-based observatories such as Paranal and Mauna Kea.

Zooniverse.org hosts most of the major citizen science astronomy initiatives. Some are easy, others more taxing, but each project will give you the necessary training before introducing you to the new data.
A personal pick is the Milky Way Project, which asks you to analyse stunning infrared imagery of the Galaxy.

ELEPHANT TOOTHPASTE

YOU WILL NEED:

- *Safety glasses*
- *Gloves*
- *Washing-up liquid*
- *Dried yeast* (*make sure that it is in date*)
- *Warm water*
- *Food colouring*
- *Empty 500ml plastic drinks bottle*
- *9% hydrogen peroxide* (*this is a mild skin disinfectant that you can buy over the counter at pharmacies*)
- *Funnel*
- *Glycerine* (*find this in the baking section of the supermarket, or in bigger bottles at a pharmacy*)

WHAT'S GOING ON?

Elephant toothpaste isn't toothpaste at all, but a foam of oxygen bubbles that have been ensnared by the washing-up liquid and thickened by the glycerine.

Chemically, hydrogen peroxide is made of two hydrogen atoms and two oxygen atoms (H_2O_2). This makes it similar to water (H_2O) but with an extra oxygen atom (O) – yet hydrogen peroxide is poisonous to living things, which is why we use it as a disinfectant, and why we keep it away from our mouths and eyes.

Yeast, however, carries a protective enzyme called catalase that destroys hydrogen peroxide. The moment the living yeast cells touch the liquid disinfectant, the enzymes go to work tearing the hydrogen peroxide molecules apart, into water and oxygen. The oxygen bubbles up vigorously to form a rapidly growing foam that erupts from the top of the bottle, such is the fervour of the reaction.

You can try this science demonstration with liver instead of yeast, as this organ also contains enzymes that destroy hydrogen peroxide.

METHOD:

1. This experiment is messy! Either work at a table that's easy to clean, or head outside.

2. The dried yeast needs to be rehydrated to 'activate' the microbes. Thoroughly mix two or three tablespoons (or one sachet) of yeast with some warm water in a bowl. Leave for a couple of minutes while you get everything else ready.

3. Put on gloves and safety glasses.

4. Pour half a cupful of hydrogen peroxide into the bottle (more if you're using a larger bottle).

5. Add a good squirt of washing-up liquid.

6. Pour in up to two tablespoons of glycerine.

7. You are going to be making toothpaste, so why not add some food colouring? I drizzled some orange food colouring down one side of the bottle and blue down the other.

8. Pour the (now activated) yeast into the bottle using the funnel.

9. Stand back as the bottle erupts with a thick foam that seems to just keep on going. It looks like toothpaste, but it's definitely not for brushing teeth with!

THE UNPOPPABLE BALLOON

You don't need a planet-sized brain to understand that a balloon plus a sharp pointy object equals a big bang. But when you up the ante, the sums don't always seem to add up, as this entertaining experiment shows…

YOU WILL NEED:

- *A packet of drawing pins*
- ***An inflated balloon*** *(have one on standby, just in case)*

METHOD:

1. Scatter a handful of drawing pins evenly over a flat surface, all pointing upwards.

2. Push an inflated balloon down onto the bed of pins.

3. Be amazed as it doesn't pop!

WHAT'S GOING ON?

We intuitively think that more spikes mean more damage, but this isn't true. One drawing pin would burst a balloon easily, but when the balloon is pressed down over many small points, pressure is spread between each one, so you need to push down much harder before any one point has the force to pierce the taut rubber. This principle also explains how circus performers can lie on a bed of nails.

You can even test the theory by walking on eggs without them cracking! Place two large boxes of eggs on the floor, making sure all the eggs are uncracked, about the same size and with their 'pointy' ends facing down. Put down some plastic sheeting if you're worried about making a mess. Take off your shoes and socks and, with someone to help you balance, ease your weight down onto both sets of eggs, spreading your weight as evenly as possible. The lighter you are, the easier it will be, so perhaps this is one just for the kids…

Dr Stuart Farrimond is a science writer, presenter and educator, and hosts a weekly science segment on BBC Radio Wiltshire. His book *The Science Of Cooking* is out later this year.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AI UPS THE ANTE

In a world first, a software agent called DeepStack has beaten a team of human pros at the most complex variant of poker yet. We meet the scientists behind it

WORDS: Dr Paul Parsons

Poker is not a game for the faint-hearted. A heady mix of bluffing and bravado, posturing and intimidation, knowing when to be cunning and when to ramp up the aggression.

At least, that's how it used to be. Now, poker's macho past could be on its way back to the locker room, thanks to the work of a team of computer scientists headed by the University of Alberta, Canada. The scientists have built a piece of artificial intelligence software called DeepStack that plays a blistering game of poker without any psychology, opponent reading or deception – just cold, hard mathematics. During November and December 2016, DeepStack trounced a group of human professionals at the most complex variant of the game yet. Some are already calling this poker's Deep Blue vs Kasparov moment. So how did the scientists build it? ▶

First of all, they studied two-player (or, 'Heads-Up') Texas Hold 'em poker. In this game, both players advance small bets (known as 'blinds') into the pot, before each being dealt two private cards. A total of five public cards are then dealt face-up, and the aim of the game is to make the strongest five-card hand using any combination of public and private cards. Dealing of the cards is interspersed by four rounds of betting. The first player to act in each round can either bet or 'check'. If they check then the action passes to the other player who has the same options. But if the first player bets, their opponent must at least match that bet (a 'call') or fold their hand. A third option is to raise the stakes, in which case the other player must call the new bet if they want to stay in. If a player folds at any time, the other wins the pot. If no one folds after all four rounds of betting, the game goes to a showdown – the players compare hands and the strongest wins.

Then, in January 2015, the Alberta team solved a 'Limit' version of Heads-Up Texas Hold 'em (where bet sizes are fixed), using an AI they developed called Cepheus. This game is characterised by 10^{14} (100,000 billion, or a 1 with 14 zeroes after it) possible decision points – unique combinations of cards dealt and bets placed, for which the optimal course of action was computed.

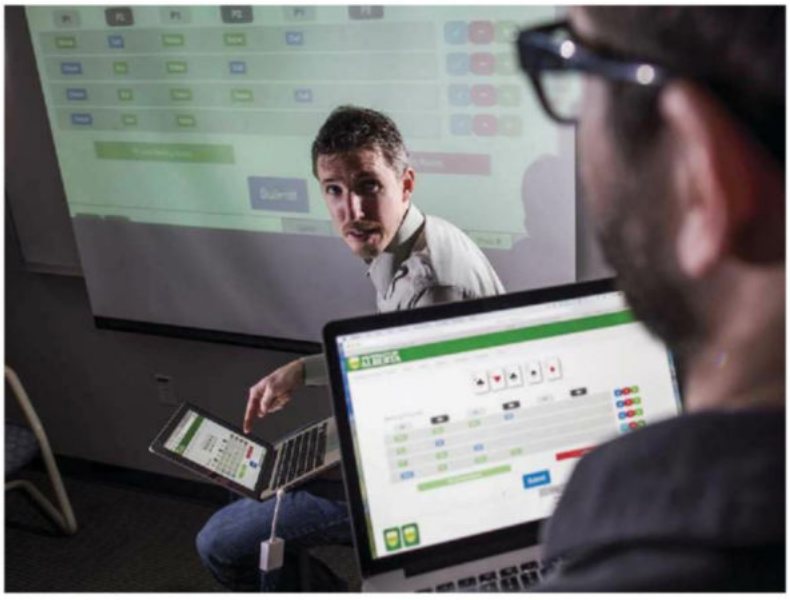
With DeepStack, they turned their attention on the vastly more complex No-Limit game where, with no restriction on bet size, there are a mind-boggling 10^{160} decision points – more than the number of atoms in the observable Universe.

For the scientists working on the project this was just as daunting as it sounds. "It was a moonshot project for us," says team member Martin Schmid, of the University of Alberta and Charles University, Prague. "Ten people worked full-time on the project for almost a year."

Their natural starting point was Cepheus. This derives its power from a concept called the Nash equilibrium, after the US mathematician John Forbes Nash. The idea is simple: play a perfect defence and just wait for your opponent to mess up. The tricky bit, at least for a game as complex as poker, is computing what this ultimate strategy actually is – a vast array of numbers dictating what course of action to take for every conceivable combination of cards and bets.

PHOTOS: GETTY, JOHN ULAN/UNIVERSITY OF ALBERTA ILLUSTRATIONS: JOE WALDRON

“DEEPSTACK PLAYS A BLISTERING GAME OF POKER WITHOUT ANY PSYCHOLOGY, OPPONENT READING OR DECEPTION – JUST COLD, HARD MATHEMATICS”



ABOVE LEFT:
Chess enthusiasts watch as Garry Kasparov – with his head in his hands – plays his sixth and final match against the computer IBM Deep Blue

ABOVE RIGHT:
The team at the University of Alberta tests out poker-playing Cepheus, the precursor to DeepStack

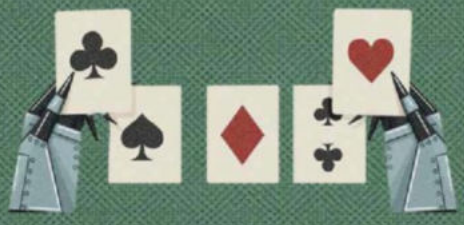
The Alberta team found the Nash equilibrium for two-player Limit Hold ’em by playing two copies of Cepheus against one another. For every decision the AI made against itself, the researchers calculated the ‘regret’ of that decision – how much better the pay-off would have been had the software acted differently. Minimising the regret led to the optimal strategy. The calculation took over three months to run on a cluster of 200 servers, clocking up 900 CPU years of computation time and generating a final strategy dataset that required 11 terabytes of disk space to store.

As DeepStack’s task was 146 orders of magnitude more complex than Limit Hold ’em, pre-calculating every possible game situation wasn’t an option. So, rather than storing pre-calculated solutions, DeepStack works out the best strategy for the current game on the fly. But doing this quickly enough to play in real time demanded some approximations. First, the researchers allowed the actions in each betting round to be fold, call, raise, re-raise and all-in (betting all remaining chips). Then they reduced the complexity of the decision tree describing the game. Every turn of the cards and every ➲

HOLD ’EM OR FOLD ’EM

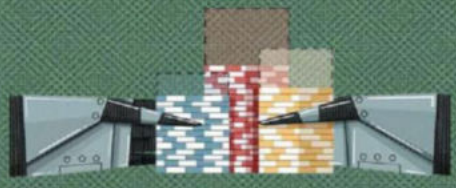
DEEPSTACK’S TOP FIVE POKER GAMBITS

SUITS
When holding two cards of the same suit, DeepStack plays more aggressively than most humans – hoping to make a flush (five cards suited) when the public cards are dealt.



COVERAGE
DeepStack plays a range of hands wide enough that it’s likely to make a strong five-card hand when the public cards come, but not so wide that it leaves itself vulnerable.

MIX IT UP
DeepStack almost never plays a situation the same way every time. Instead it assigns probabilities to each action (raise, fold, call) and then randomises its play accordingly, keeping its opponent guessing.



BET SIZE
While humans adapt their bet sizes to the situation, influencing the odds and their opponent’s play, DeepStack dominates with a small bet range – fold, call, pot-sized bet, half pot, twice pot and all-in.

LIMPING
Calling your opponent’s bets before the public cards are dealt, known as limping, is seen as weak in heads-up poker – raising or folding is considered stronger. But DeepStack limps frequently.

action creates a branching point in the possible future outcome of a poker hand, where the action can unfold differently. The further into the future of a hand you look, the more branches there are, and the harder the calculation will be. The researchers limited the depth of their future decision trees to just four branching points. "While solving the look-ahead tree, you use some function at the end of the tree to estimate values farther below. We used deep neural networks," says Schmid.

A neural network is a piece of software that simulates biological brain cells and the connections between them. The team constructed neural networks with thousands of virtual brain cells and trained them against randomly generated poker situations and their corresponding regret values. The idea is that the network can look at any given game situation and use what it has learned to spit back a fast, accurate estimate of the regret – so the best course of action can be selected.

"HUMANS BELIEVE THAT PSYCHOLOGY, BRAVERY OR BALLS PLAY A ROLE. ACTUALLY, IT'S ALL MATH AND GAME THEORY"

These measures all taken together reduced the complexity of Heads-Up No Limit Hold 'em from 10^{160} decision points down to just 10^{7} (10 million) – simple enough that actions could be calculated on an ordinary desktop PC, running a single NVIDIA GeForce GTX 1080 graphics card, in less than five seconds. DeepStack was in business.

To put the software through its paces, the team recruited 33 professional poker players. They were each tasked with completing 3,000 online hands of Heads-Up No-Limit Hold 'em against DeepStack, between Nov 7 and Dec 12, 2016 – with cash prizes offered to the three players who performed best.

Performance was measured in milli-big-blinds per game (mbb/g), where the 'big blind' is the larger of the two bets that players must advance before any cards are dealt. A human pro who can average winnings of at least 50mbb/g is considered competent. Each player's final profit/loss figure was adjusted to account for how lucky or unlucky their cards had been. Of the 11 players who completed the required 3,000 hands, all finished with a loss on the luck-adjusted scale, while eight of them were beaten on the unadjusted scale. DeepStack averaged overall winnings of 394mbb/g (luck adjusted) and 429mbb/g (unadjusted) against these 11 players.

Irish poker pro and former electronics engineer Dara O'Kearney was among those who participated in the challenge. "I went in to the match assuming it would play in a style close to

FIVE OTHER GAMES WHERE AI WILL THRASH YOU...

NOUGHTS & CROSSES

Also known as tic-tac-toe, and immortalised in the 1983 movie *WarGames*, this was solved in 1972 by computer scientists Allen Newell and Herbert Simon. Hint: always open the game on a corner.

VIDEO GAMES

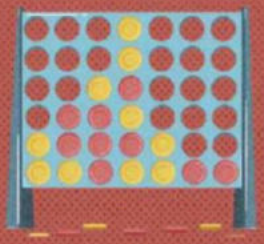
Google's DeepMind AI has mastered a number of Atari 2600 classics, including *Space Invaders*, *Pong*, *Breakout* and *Video Olympics*. The team behind the AI now has its sights on strategy game *StarCraft*.

BACKGAMMON

TD-Gammon was a backgammon-playing neural network, developed in 1992 by Gerald Tesauro at IBM's Watson Research Center, New York. It was able to beat all but the world's top professional players.

DRAUGHTS

Also known as checkers, this was cracked in 2007 by Jonathan Schaeffer at the University of Alberta, Canada. Thanks to the 10^{20} possible board positions, it was a mammoth computer calculation that took 18 years to run.



CONNECT 4

A strong, game theory-based solution of *Connect 4* was formulated by computer scientist John Tromp at the University of Amsterdam in the 1990s. Try your luck against it here: **connect4.gamesolver.org**

ABOVE: **Matej Moravčík, Martin Schmid and Michael Bowling from the University of Alberta's computer poker research team**

game theory optimal, bluffing the correct frequencies with the optimal types of hands, and it conformed to this," he says. "Had I not known it was a bot I don't think I'd have realised."

Unlike other games that have been beaten by artificial intelligence agents, such as chess and Go – where all the information about the state of the game is available to both players – poker is a game of imperfect information. This means that DeepStack's underlying algorithms could have profound applications in real situations where some information is hidden, in fields such as defence, negotiation, economics, and even medical diagnosis. "Game theory is already being used by the US Coast Guard and Los Angeles Airport Police," says team member Matej Moravčík. "The DeepStack algorithm makes it possible to reason very well in substantially larger games."

Back at the gaming table, O'Kearney believes DeepStack's achievement outstrips the historic 1997 victory of chess computer DeepBlue over grandmaster Garry Kasparov. "Poker is a more complex game than chess in terms of size of the game tree," he says. "It's also a game where humans have a misguided belief that certain human traits like psychology, bravery or balls play a larger role. Actually it's all math and game theory, as AI's ability to master it proves."

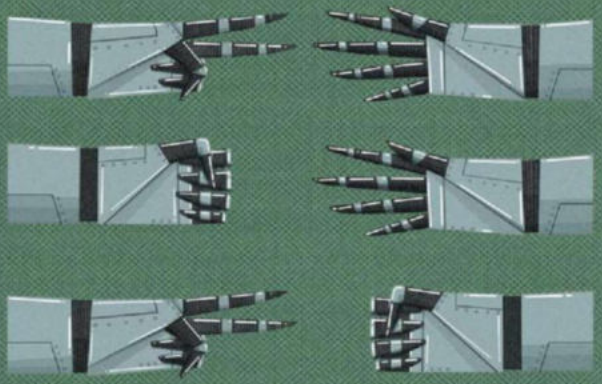
Dr Paul Parsons is a science writer, and an analyst at BetVictor.

DISCOVER MORE

Find out more about the DeepStack project at **deepstack.ai/** Watch DeepStack play live against poker pros every Wednesday:**twitch.tv/deepstackai**

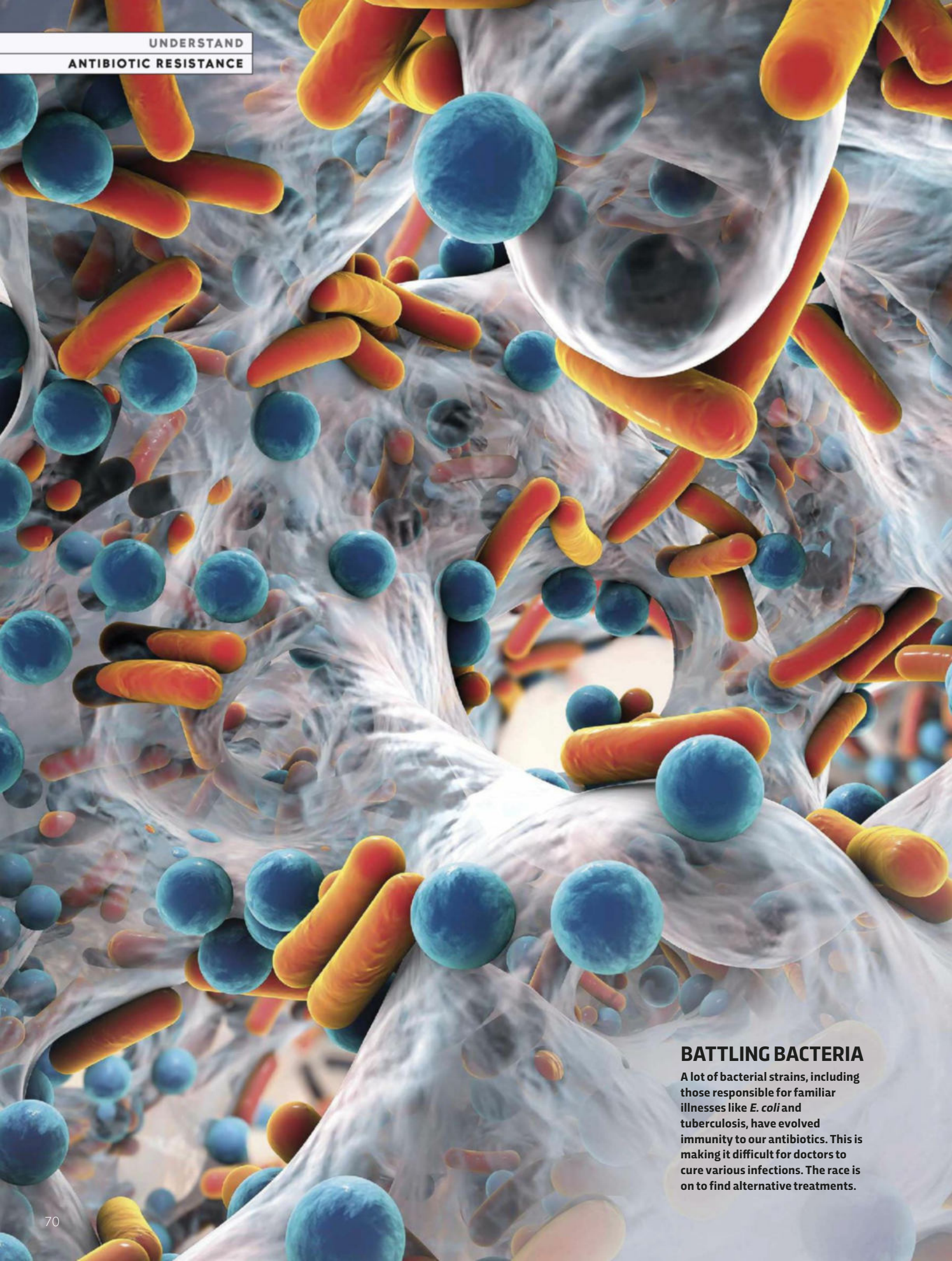
NO REGRETS

REGRET MINIMISATION SOLVES AN OLD GAME



The Alberta team train their poker programs using a technique called 'regret minimisation'. This works by calculating how much better off the program would be had it acted differently, and then tweaking its strategy until this regret is minimised. It turns out the same technique can find unexploitable strategies for other games too. One example is rock-paper-scissors. Imagine the stake is £1 per game. My strategy is to play 'rock' 100 per cent of the time whereas my opponent always plays 'paper'. Clearly, I'm going to lose £1 every time and regret not playing 'scissors'. But if I now switch to playing 'scissors' all the time, although I'll briefly start winning, my strategy is exploitable – because my opponent will soon get wise and start playing 'rock'. However, minimising the total regret leads to a strategy where 'rock', 'paper' and 'scissors' are each played randomly one-third of the time. And this is unexploitable – in the long run, a player adopting this strategy cannot lose.

PHOTO: JOHN ULAN/UNIVERSITY OF ALBERTA ILLUSTRATIONS: JOE WALDRON



BATTLING BACTERIA

A lot of bacterial strains, including those responsible for familiar illnesses like *E. coli* and tuberculosis, have evolved immunity to our antibiotics. This is making it difficult for doctors to cure various infections. The race is on to find alternative treatments.

UNDERSTAND ANTIBIOTIC RESISTANCE

It's one of the greatest threats to humankind, so what can we do about it?

WORDS: **TOM IRELAND**

If you're a fan of apocalyptic disaster movies, you'll be familiar with all manner of things that might bring about the fall of civilisation: asteroid strikes, deadly viruses, alien invasions, nuclear armageddon. Perhaps even an outbreak of zombies.

B what about antibi ic resi an Experts now believe that the spread of drug-resistant bacteria is probably the single greatest threat to society – greater even than the dangers posed by global terrorism, climate change and anything you'll see at the cinema.

There are signs that this 'antibiotic apocalypse' is already upon us: in Europe and the US alone, at least 50,000 people die each year from infections that don't respond to conventional treatment. Antibiotic-resistant bacteria have been found in every country. If current trends continue, all the world's antibiotic medicines could effectively be useless in just a few decades. According to a report by the *Review On Antimicrobial Resistance*, failure to tackle the problem could cause the world's population to fall by almost half a billion by 2050 and cost the global economy $100tr.

Why are antibiotics important?

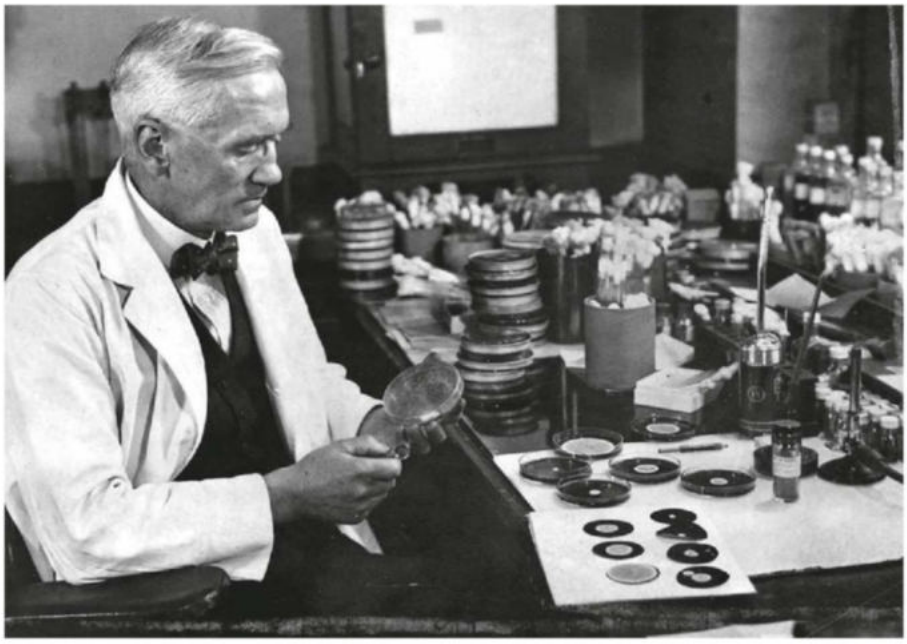
Antibiotics kill or inhibit the growth of bacteria, helping us to treat both minor and serious bacterial infections. They are used in all areas of medicine, including the treatment of skin conditions such as acne; more serious infections like food poisoning or pneumonia; and deadly contagious diseases such as tuberculosis and meningitis. Antibiotics also stop wounds getting infected after an injury or an operation, and help protect people with damaged immune systems, such as patients undergoing cancer treatment or individuals who have recently received an organ transplant.

There are hundreds of different types of antibiotic, from creams to pills to injections, each developed to target different infections caused by different types of bacteria. Since their introduction around 75 years ago, antibiotics have added approximately 20 years to the average life expectancy across the globe. Life before these wonder drugs was scary – anything that caused an infection could kill you, even a paper cut. In the centuries before modern antibiotics, it's believed that around 40 per cent of all deaths were caused by untreated infections. And if an infection didn't kill you, it could leave you scarred or disfigured.

How do antibiotics work?

Antibiotics are chemicals that disrupt key processes in bacterial cells. To be safely used as a drug, they must specifically affect bacterial cells without damaging human tissue. The first modern antibacterial, penicillin, was discovered in 1928 by Scottish scientist Alexander Fleming. Produced by a fungus found in mould, penicillin causes the walls of bacterial cells to fail. Human cells do not have these rigid cell walls, so are unaffected by penicillin, and many similar drugs have been developed over the decades.

Other antibi ics in rfere with processes that are essential for ▶



Alexander Fleming discovered penicillin, which went on to transform the world of medicine

PHOTOS: GETTY, SCIENCE & SOCIETY

MRSA colonies grown on an agar plate in a lab

bacteria to grow, such as the production of proteins, DNA, or energy.

How do bacteria become resistant?

Although it seems like bacteria are in some way 'learning' how to fight back against us, the development of antibiotic resistance is an inevitable and natural part of bacterial evolution.

Each time a bacterium multiplies, it divides into two and copies its DNA. Imperfections in this process mean that in a population of millions, billions or even trillions of multiplying bacterial cells, there are lots of 'mistakes', known as mutations, in the DNA of each successive generation.

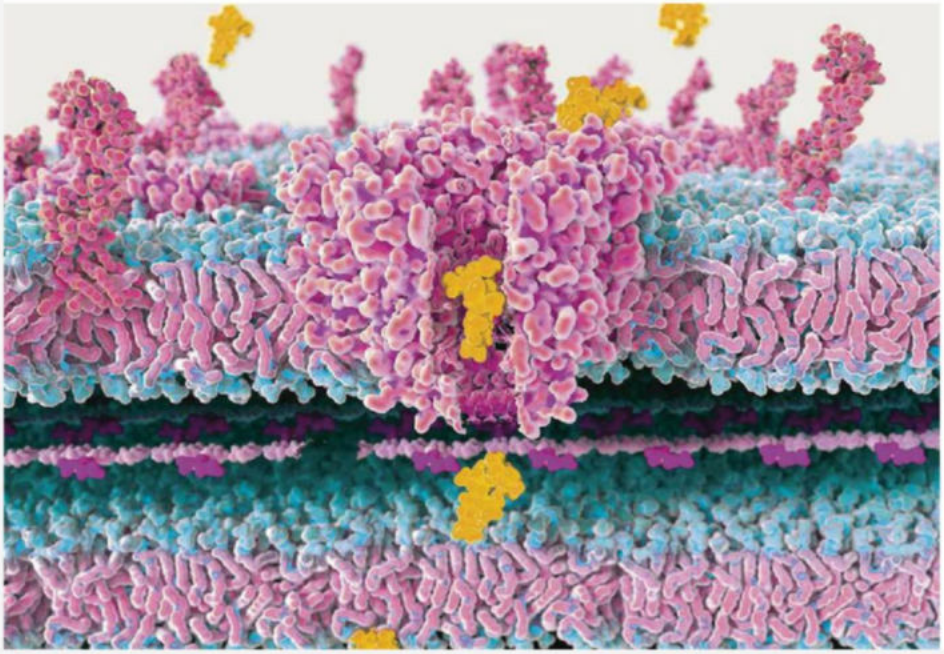
Owing to the sheer number of variants, over time a tiny proportion of individuals will, by chance, develop a quirk that means they are immune to certain antibiotics. A mutation may, for example, subtly change the structure of a key molecule that the antibiotic targets, rendering it ineffective. Or, it may mean the bacteria start producing a chemical that destroys the antibacterial properties of the drug. In the case of penicillin, many bacteria have evolved to produce chemicals known as beta-lactamase enzymes, which neutralise the drug's effect.

Once it emerges, antibiotic resistance can jump from one species of bacteria to another. Microorganisms naturally exchange genetic material in a process called horizontal gene transfer – either by close contact or by forming a sort of bridge between each other. This helps bacteria shuffle their DNA and 'share' useful genes, but often causes the genes responsible for antibacterial resistance to jump from harmless bacteria into more deadly types.

As if drug-resistant bacteria weren't enough of a problem, resistance can also emerge in viruses, fungi and parasites. This is known as *antimicrobial* resistance, or 'AMR'. Even insects and weeds are developing resistance to the chemicals we use to destroy pests and keep crops healthy.

How does resistance spread?

Antibiotic resistance becomes a big problem when antibiotics are overused. Using an antibiotic destroys a lot of bacteria in a person's body – both good and bad strains. This means bacteria that are resistant to the antibiotic are free to colonise that space and multiply without competition. This can cause illnesses in the person affected, but also means they will be carrying huge numbers of antibiotic-resistant germs, which are then passed on to other people. Hospitals act like a sort of transport hub for antibiotic-resistant genes: antibiotics are used heavily, concentrating resistance genes in the



An antibiotic (pink) passes through the bacterial cell wall. This will kill the bacterium

JARGON BUSTER

AMR
AMR, or antimicrobial resistance, is a broad term that includes the emergence of resistance in bacteria, as well as in other microorganisms such as viruses and fungi.

BETA-LACTAMASE
Bacteria that can produce beta-lactamase are a major threat to healthcare systems worldwide. This chemical blocks the action of a key family of antibiotics that act on the bacterial cell wall.

HORIZONTAL GENE TRANSFER (HGT)
As well as passing on DNA to successive generations, bacteria can also exchange DNA with unrelated microorganisms nearby. This allows them to 'share' useful genes, helping resistance spread from one species to another.

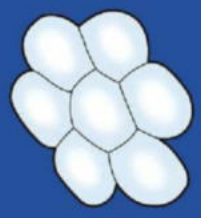
MDROs
'Multi-drug resistant organisms' are strains of bacteria that are resistant to lots of antibiotics. Some are resistant to 'last resort' drugs.

MRSA
Methicillin-resistant *Staphylococcus aureus* is a common bacterium that has developed resistance to many types of penicillin-style antibiotics. It is one of several strains that have become known as 'hospital superbugs'.

MUTATION
Each time a bacterium divides, its DNA is copied imperfectly and there is a chance it will develop a DNA mutation that is useful – such as resistance to antibiotics.

THE 9 MOST DANGEROUS ANTIBIOTIC-RESISTANT BACTERIA

Earlier this year, the World Health Organization released a list of the world's most dangerous bacteria. Nine are classified as being either a high or critically high priority for the development of new antibiotics...



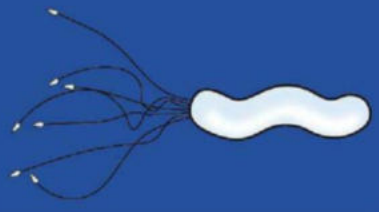
Acinetobacter baumannii
This can cause pneumonia, as well as wound and blood infections in people with compromised immune systems.

Enterobacteriaceae
Feared as the next superbug, Carbapenem-resistant Enterobacteriaceae kill up to half of patients who get infected by them.

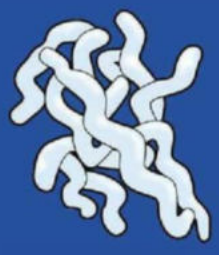
Enterococcus faecium
This bacterium causes urinary tract and blood infections. It's developed six types of resistance to the antibiotic vancomycin.

Pseudomonas aeruginosa
Resistant to 'last resort' antibiotics, this bug can cause fatal infections in vulnerable patients.

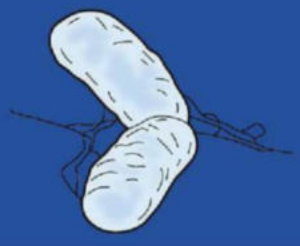
Staphylococcus aureus (MRSA)
MRSA lives harmlessly on the skin of around 1 in 30 people, but can cause fatal infections if it goes deeper into the body.



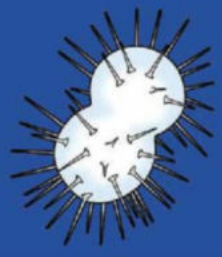
Helicobacter pylori
Often the cause of stomach ulcers, a mutation makes the most common treatment, clarithromycin, ineffective.



Campylobacter spp.
Campylobacter is found in raw meat and causes food poisoning. It is increasingly resistant to fluoroquinolone.



Salmonellae
The many thousands of strains of *Salmonella* can cause illnesses such as typhoid fever and food poisoning.



Neisseria gonorrhoeae
Responsible for the sexually transmitted infection gonorrhoea, antibiotic resistance has been noted since the 1940s.

WHAT WE STILL DON'T KNOW

1 HOW LONG DO WE HAVE?

As the development of antibiotic resistance is based on chance mutations and random transfer of genetic material, it's hard to predict when and where resistance will emerge, and how much time we have left to find solutions. However, new tools are being deployed to help identify and monitor 'hotspots' of resistance around the world.

2 CAN WE TACKLE IT GLOBALLY?

In many ways, our efforts to curb antibiotic resistance have parallels with climate change: the most advanced efforts in one country are worth nothing if other countries continue as they are. The Western world has made significant progress, but telling developing or poorer nations that they now cannot use antibiotics is not going to be easy.

3 WHEN WILL WE HAVE NEW DRUGS?

It's unclear how successful research into new antibiotics, and new strategies for extending the life of existing antibiotics, will actually be. New drugs can take decades to be proven to be safe for widespread use, and cost millions of dollars to develop. After all that research, bacteria may evolve methods to bypass these new systems anyway.

ILLUSTRATION: ACUTE GRAPHICS

In one tweet...

Antibiotics have revolutionised healthcare & expanded lifespans. But overuse of these valuable drugs puts all modern medicine at risk #AMR

Without antibiotics, even routine operations would become incredibly risky

ward. These are then passed on to staff, other bacteria and patients.

The more often antibiotics are used, the more likely it is that drug-resistant bacteria will come to dominate in any given location. And it's not just human medicine that helps spread antibiotic resistance. In some countries, antibiotics are often routinely administered to livestock to boost growth or to prevent infections spreading throughout herds, which means bugs with genes for resistance are passed back to humans via contaminated meat, animal products, or crops fertilised with manure.

Even in countries with excellent hospital hygiene and strict regulations for preventing the overuse of antibiotics, people and goods from places with poor antibiotic practices are only a short plane flight away.

What if antibiotics stopped working?

First, deaths from bacterial infections like tuberculosis and meningitis would undoubtedly rise. Infections that we don't currently think of as deadly would also start to cause serious illnesses and deaths. Even trivial conditions like abscesses or spots would become difficult to treat, meaning that ugly sores and strange skin conditions w ld become a common sight, like in medieval times.

But the effect on healthcare would be even more profound. Each year, billions of operations are carried out around the world, and almost all of them require antibiotics to prevent infections during and after the procedure. One in four births in England is by c-section, where antibiotics protect mum and baby.

Without antibiotics, the risk of dying from an infection after these procedures might mean they simply aren't worth it. The vast cost of trying to cure difficult-to-treat infections might have crippled many nations' health services by then anyway. If antibiotics no longer work, we may have to change the way we behave completely.

How worried should we be?

Pretty worried! Many strains of bacteria have acquired resistance to more than one type of antibiotic. These strains of bacteria, known as multi-drug resistant (MDR) organisms or 'superbugs', are already putting a strain on the world's healthcare systems.

Prof Dame Sally Davies, the UK's chief medical officer, said recently that the golden era of ever-increasing life expectancy may soon give way to an era where mortality rates start to increase. She told a government inquiry on antibiotic resistance that she was far more worried about "dying in an operating theatre during a routine operation" than climate change. Hospitals are struggling to rid wards of multi-drug resistant bacteria such as MRSA (methicillin-resistant *Staphylococcus aureus*), while 'extensively drug-resistant tuberculosis' (XDR-TB) has now been identified in 100 countries, causing over 200,000 deaths each year. In *E. coli* bacteria, a common cause of food poisoning, resistance to antibiotics is now so widespread that conventional treatment is ineffective in more than half of patients.

And strains of bacteria have been found that are resistant to our 'last resort' antibiotics. Treating patients who have these dangerous bacteria is difficult, hazardous and expensive.

Experts have predicted that if trends continue, existing antibiotics could be almost useless in as little as 20 years.

Can't we just develop new antibiotics?

For decades, resistance was relatively rare and the pharmaceutical industry was constantly making new types of antibiotics. But by the 1990s, drug companies were starting to run out of new ways to kill bacteria that didn't involve harming human cells. Many efforts to find new drugs resulted in compounds that were similar to existing antibiotics, and so resistance to these developed quickly, too. Most of the antibiotics used around the world today are virtually the same as ones developed 30 years ago.

The biggest problem now is money. It can cost anywhere between $500m and $2bn to discover a new drug and bring

PHOTO: GETTY

IN A NUTSHELL

1 LIFE SAVERS

Antibiotics kill the bacteria that cause infections and diseases. They're used in billions of operations, and without them, an infection caused by something like a paper cut could prove fatal.

2 THE DRUGS DON'T WORK

As bacteria are constantly multiplying, a small number of cells will emerge now and again with a DNA mutation that gives them a kind of immunity to an antibiotic. The more drug-resistant bacteria there are, the more dangerous infections become.

3 THE RACE IS ON

Scientists are on the lookout for new antibiotics and alternative ways to fight infections. Meanwhile, GPs and patients are being encouraged to curb their use of the drugs. The Longitude Prize is offering £10m for anyone who can develop a cheap, accurate and easy-to-use test for bacterial infections, helping to reduce the number of misdiagnoses and prescriptions.

Handwashing can help reduce the spread of bacteria

it to market, yet these new antibiotics will either be saved for use as a last resort or will become useless when resistance to them develops. This means there is little incentive for pharmaceutical companies to focus their efforts in this area.

However, there is some good news: scientists at the Scripps Research Institute in the US recently announced that they have modified a common antibiotic, vancomycin, so that it now attacks bacteria in three different ways. The researchers say the drug could be used widely without fear of resistance as it's so unlikely that bacteria could evade three modes of action at once.

Are there alternatives to antibiotics?

Scientists are starting to combine antibiotics with compounds that disrupt whatever adaptation the resistant bacteria have developed. For example, if a bacterium has started producing a protein that stops an antibiotic entering its membrane, researchers can develop a 'decoy' compound to block that protein. The patient takes a combination of the antibiotic and the decoy, and the antibiotic suddenly works again.

Another alternative to conventional antibiotics is a treatment that has been used in Russia and Eastern Europe since the 1940s but for a long time was not taken seriously in the West. Known as phage therapy, it uses viruses to hijack bacteria and destroy them from the inside. While it may sound dangerous, the viruses used – known as bacteriophages – naturally attack bacteria and bacteria only.

Other potential avenues for research include drugs that help the immune system to identify and attack bacteria, the use of bioengineered nanoparticles or viruses to bombard bacteria, and the use of probiotic, 'friendly' bacteria to outcompete the nasty ones.

The problem with all of these potential solutions? Bacteria could develop resistance to any of these treatments eventually, too.

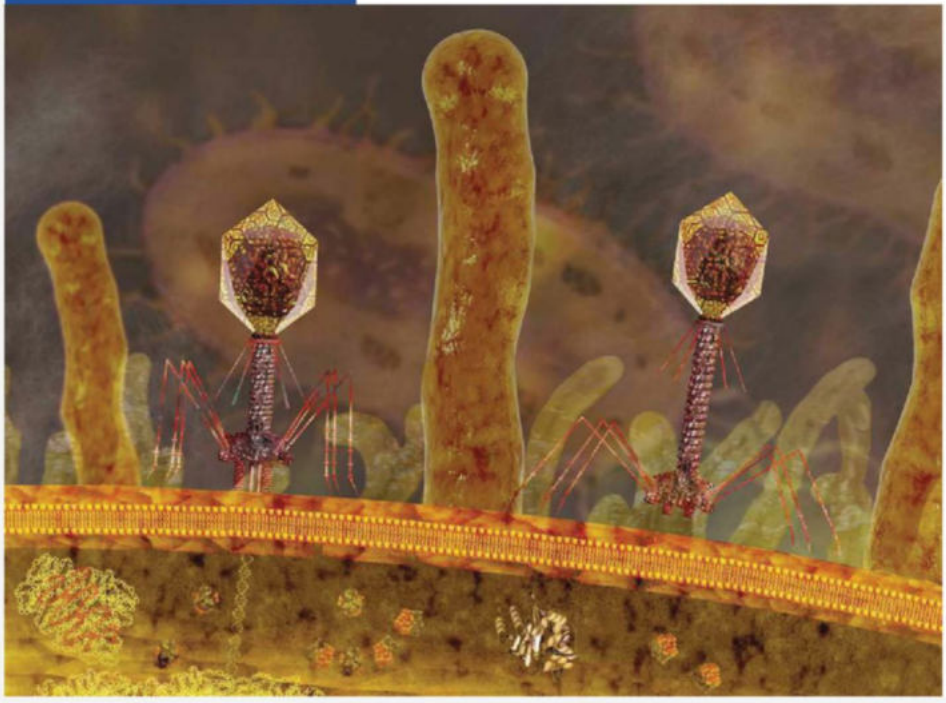
What else can we do to stop it?

Due to the ease with which people can travel around the world, containing the spread of antibiotic resistance requires coordinated global action. To preserve the potency of existing antibiotics, their use must be curbed: they must be prescribed only for bacterial infections, and in the proper dose, for the correct amount of time.

Lots of research is being directed at tests which will allow GPs to quickly diagnose whether an illness requires antibiotics or not, and this should help encourage more targeted use. Other research is looking at ways to interfere with how bacteria swap DNA, to try and eliminate the spread of resistance genes between bacteria.

On an individual level, regular handwashing and general good hygiene helps reduce the spread of bacteria and therefore the need for antibiotics. People are encouraged not to pressure doctors or pharmacists into giving them antibiotics without knowing for sure what is causing their illness.

In short, the whole of society must start to appreciate these valuable drugs more. The more we use them, the less effective they are.



BELOW: **Vir can be used to infect bacteria**

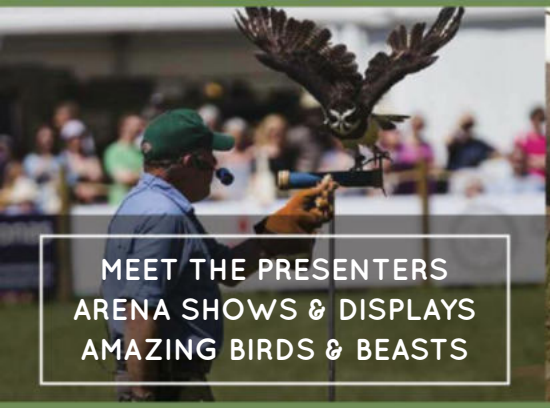
PHOTOS: ALAMY, SCIENCE PHOTO LIBRARY

Tom Ireland is a science writer and editor of *The Biologist*. He tweets from @Tom_J_Ireland.

EXPLORE THE BEST OF BRITAIN'S COUNTRYSIDE IN ONE AMAZING DAY OUT

'An amazing event with something for everyone'
Visitor

'An extraordinary cultural phenomenon'
The Daily Mail



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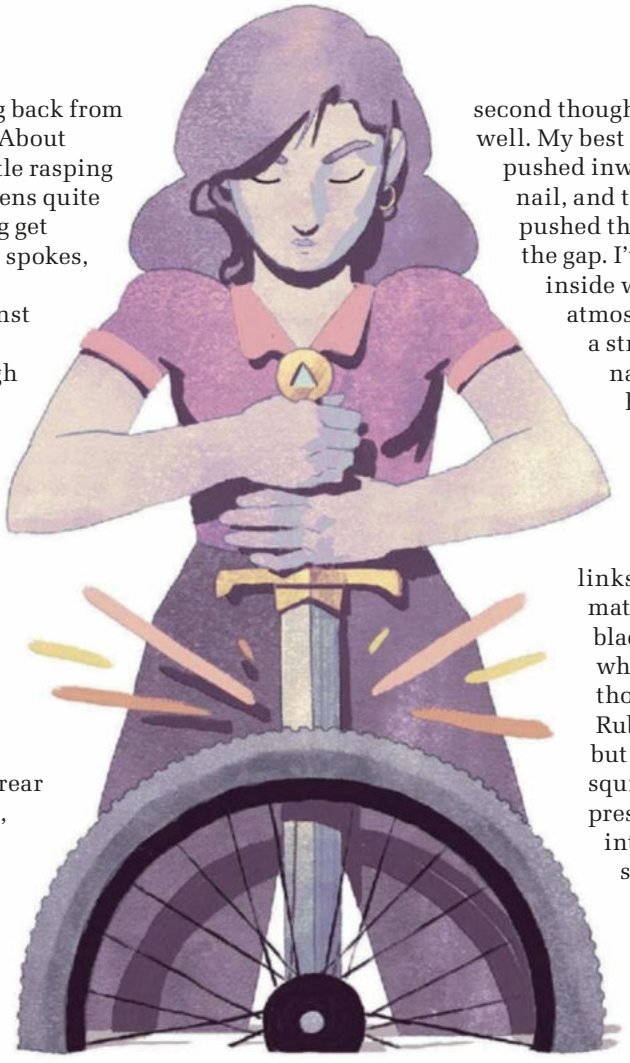
HELEN CZERSKI ON... TYRE PUNCTURES

"THE NAIL HAD GONE THROUGH BOTH TYRE AND INNER TUBE, TWICE, AND HAD RE-SEALED QUICKLY"



Recently, I was cycling back from my badminton club. About halfway home, a gentle rasping sound began. It happens quite a lot – leaves or a twig get stuck somewhere in the rear wheel spokes, and then once every rotation the uninvited hitchhiker brushes against the reflector or the brakes. I was hungry and in a hurry, and although I peered back at the wheel every time I stopped at traffic lights, I couldn't spot the twig and wasn't bothered enough to have a proper look. The soft swish, swish, swish sound followed me home. It was only when I was inside the bike cage at my flat that I gave it my full attention. What I found made me gasp out loud. And, because this is 2017, it also made me reach for my phone and start taking pictures.

A 4cm-long nail had pierced the rear tyre and had gone straight through, re-emerging close to the rim. The tyre was still at full pressure, and the swishing sound had come from the spiky end of the nail grazing against the brake block. Some bike wheels now have swanky insides, lacking an inner tube or filled with gloop that's supposed to automatically bung up puncture holes, but not this one. The nail had gone through both tyre and inner tube, twice, and had re-sealed so quickly that I had cycled three miles on it without noticing. After poking at the tyre for a bit in disbelief, I used my keys to lever the nail out. Four seconds of the sort of hiss usually associated with an extremely angry viper, and the tyre was as flat as a pancake. When I extracted the inner tube, it had two neat round holes in it, almost as if fangs had done the deed.

My first thought was to wonder how much further I could have cycled without it deflating. And my second thought was about how it had sealed so well. My best guess is that the inner tube was pushed inward to create a skirt around the nail, and that the pressure inside the tyre pushed the rubber against the metal to seal the gap. I've got a road bike, so the pressure inside was close to seven times atmospheric pressure – enough to form a strong seal. That might explain the nail going in, but I can't quite see how it would work on the way out.

I can see the foundation of the solution, because this type of seal is pretty common. Rubber is formed from stretchy polymer chains locked together with cross-links. In tyres and inner tubes, this matrix is reinforced with carbon black to make it more durable (that's why tyres are always black, even though natural rubber is white). Rubber will deform when squeezed, but it won't get smaller – it just squishes out sideways. So if you apply pressure, a rubber matrix will squish into all the tiny gaps in nearby surfaces, forming a perfect barrier. But how exactly did that work, twice, inside my inner tube?

The most frustrating thing about all this is that even though I'm a huge fan of experiments to help understand a situation, I can't imagine being able to recreate this one. I could cycle over beds of nails for months, and never get a double puncture like this again. I could look right at that nail, but I couldn't see what was just on the other side of the tyre, forming the seal. So this one is unfinished business, to be stored away in the pile of not-quite-solved scientific puzzles. But you never know when a new nugget of understanding will boot one of those mysteries out into the open again. Tyres, I'm watching you...

Dr Helen Czerski is a physicist and BBC presenter. Her latest book is *Storm In A Teacup*.

NEXT ISSUE: PATTERNS OF LIGHT

ILLUSTRATION: KYLE SMART

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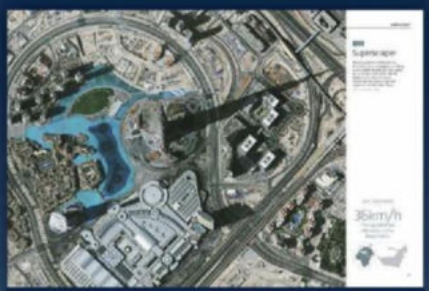

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Q&A

DR ALASTAIR GUNN
Astronomer, astrophysicist

ALEXANDRA CHEUNG
Environment/ climate expert

DR PETER J BENTLEY
Computer scientist, author

PROF ALICE GREGORY
Psychologist, sleep expert

PROF MARK LORCH
Chemist, science writer

CHARLOTTE CORNEY
Zoo director, conservationist

DR HELEN SCALES
Oceans expert, science writer

DR CHRISTIAN JARRETT
Neuroscientist, science writer

EMMA DAVIES
Heath expert, science writer

LUIS VILLAZON
Science/tech writer

DR AARATHI PRASAD
Biologist, geneticist

PROF ROBERT MATTHEWS
Physicist, science writer

YOUR QUESTIONS ANSWERED

SUMMER 2017 | EDITED BY EMMA BAYLEY

PHOTO: GETTY

How do young babies know how to swim underwater?

GARY BARKER, DURHAM

They don't. The baby on the cover of Nirvana's iconic album *Nevermind* is holding its breath, but it isn't swimming. The breathing response is automatic and part of the mammalian diving reflex. All mammals will automatically close off their trachea and slow their heart rate when their face is immersed in cold water. But human babies younger than four months aren't strong enough to make effective swimming movements or keep their head above water. **LV**

Do crows actually fly in a straight line?

MARY WOODS, CHICHESTER

Not especially. It's true that they don't swoop through the air like starlings or swallows, but crows can often be seen circling above their nests on a winter's afternoon. The phrase comes from the 18th Century, and probably simply stems from the fact that crows are large, noisy, conspicuous birds often seen flying alone across open countryside. A related phrase to 'as the crow flies' is 'making a beeline', but bees don't fly in particularly straight lines, either. **LV**

Do tea and coffee dehydrate you?

LIZZIE WRAY, BOURNEMOUTH

Health experts often warn of the need to keep hydrated, but some insist tea and coffee don't increase hydration levels. That's supposedly because they contain caffeine, which makes us urinate more. But while caffeine can have a diuretic effect, a 2016 study by a team from various UK universities showed the amounts in tea and coffee had negligible impact. **RM**

IN NUMBERS

2.48 million

The Scoville units packed inside the world's hottest chilli, Dragon's Breath.

25 billion

The number of galaxies in the largest ever virtual universe.

3

The number of people who die from asthma attacks in the UK every day.

QUESTION OF THE MONTH

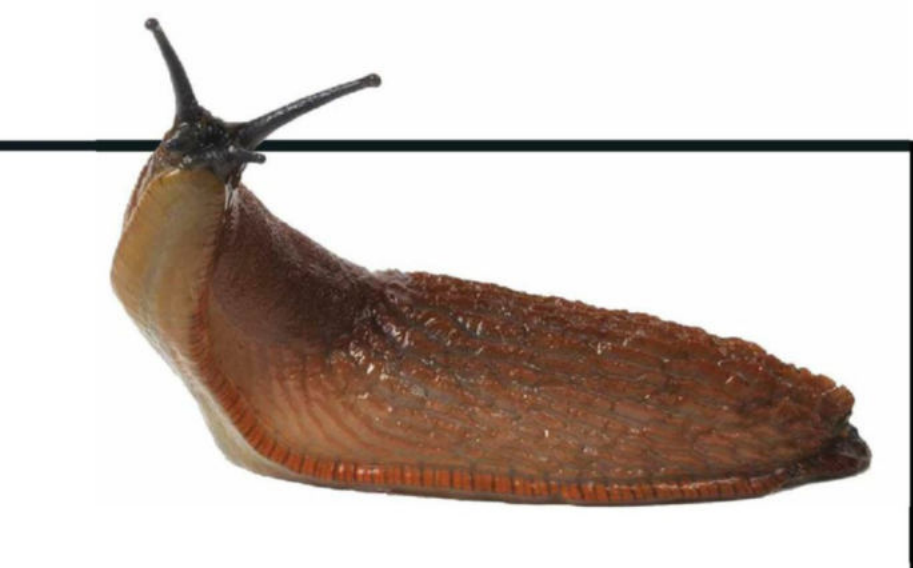
Could humans evolve to adapt to Mars?

CLAIRE PRICE, MERTHYR TYDFIL

Evolve by natural selection? Definitely not. Genes to help deal with radiation and low gravity aren't impossible, and eventually humans would probably evolve these adaptations. But evolution won't help us with the Martian atmosphere. Natural selection needs an environment that kills the weak but lets the strong survive. Mars has almost no atmosphere and none of it is oxygen, which means that it is 100 per cent fatal to everyone. You'll have three minutes to evolve to breathe CO_2 before you suffocate, and after that you won't make any further contribution to the gene pool. Even if you kept Mars colonists inside a pressurised dome and ever so gradually reduced the pressure and oxygen concentration over hundreds of thousands of years, it wouldn't help us to evolve. Natural selection might evolve better and better ways to manage on what little oxygen there was, but it is never going to give us cells that don't need oxygen at all. We burned that evolutionary bridge two billion years ago. We will adapt to life on Mars by using technology, and it would actually be easier and faster to add oxygen to the Martian atmosphere, than for us to evolve to live without it! **LV**

WINNER!

Claire Price wins a DIY Synth Kit and DIY Speaker Kit (**techwillsaveus.com**). The synth kit (£25) enables you to build a synthesiser to make electronic music from scratch, while the speaker kit (£28) will let you create your very own portable speaker.



Why don't slugs have shells?

SALLY THOMPSON, BURNLEY

Slugs belong to a group of animals called molluscs. While slugs have no apparent shell, some species may have a reduced shell, or one that is internal, and therefore not visible. It is believed that the first mollusc-like animals were shell-less, with reduced or internal shells emerging later, and external shells evolving after that. This may seem strange, as molluscs have soft bodies, making them easy, vulnerable prey. But while shells do give some protection, they can also slow you down, so molluscs have extremely diverse survival strategies, which include camouflage, colouration, detaching their back appendages (as some lizards do) and chemical defences. **AP**

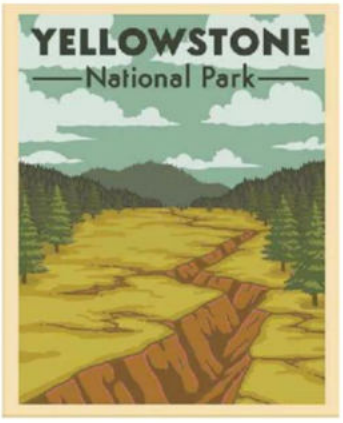
Do UV lights in nightclubs give you vitamin D?

NIC ALFORD, ILFRACOMBE

No, for two reasons. First, UV lights in nightclubs typically output at a wavelength of 365nm or longer. This is at the visible end of ultraviolet (which is why you can see a faint purple tinge to the light) and it isn't energetic enough to trigger vitamin D synthesis. You need UVB light with wavelengths shorter than 315nm for that. Second, indoor lights are only one-thousandth as bright as normal daylight. LV

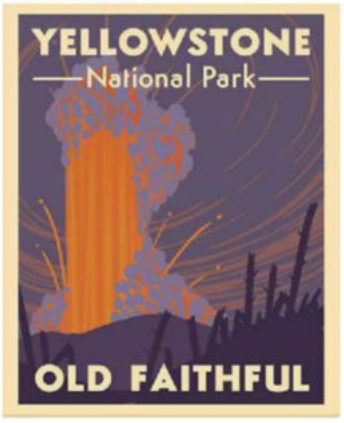
THE THOUGHT EXPERIMENT

WHAT WOULD HAPPEN IF THE SUPERVOLCANO UNDER YELLOWSTONE ERUPTED?



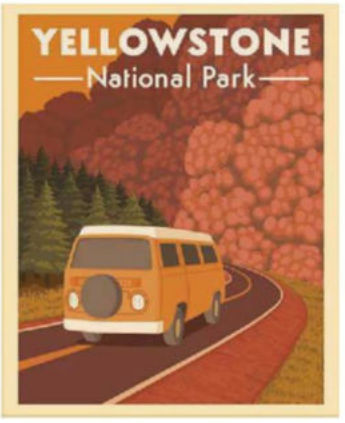
1. EARTHQUAKES

Months of earthquakes would culminate in a huge quake, creating fissures to the magma chamber 7km below. As pressure is released, gases dissolved in the magma come out of solution, turning the magma into a boiling froth.



2. BLASTWAVE

The total energy released would be equivalent to an 875,000 megaton explosion. The shockwave would kill 90,000 people. Most of the lava would fall back into the crater. Any flows would be slow and only spread 40-50km or so.



3. ASH FLOWS

More dangerous are the pyroclastic flows – clouds of dense, hot ash flowing outwards from the vent. A 2016 study found that the flows would probably move at 16-72km/h. That's slow enough that you could outrun the ash in a car.

4. VOLCANIC WINTER

The US would be blanketed with ash – up to a metre deep in Salt Lake City. This would cause respiratory problems. Two hundred million tonnes of sulphur dioxide carried into the stratosphere would cool the climate for a decade.

PHOTOS: ALAMY, GETTY X4 ILLUSTRATIONS: RAJA LOCKEY

Does metal corrode or rust in space?

BRIAN HOPE, BIRMINGHAM

Surprisingly, yes. Earth's atmosphere still contains oxygen up to about 700km altitude (the ISS orbits at 400km). At that altitude, oxygen exists as single atoms, rather than O_2 molecules, and it is more reactive. Aluminium and stainless steel form a protective oxide layer and won't corrode, but silver and iron corrode quickly in low orbit. In deep space, however, the lack of oxygen means that corrosion does not occur. **LV**

Former Soviet leader Mikhail Gorbachev has one of the most iconic birthmarks out there

Are birthmarks hereditary?

ALISTER KENNEDY, AYRSHIRE

Almost all newborn children have some sort of birthmark. They are not hereditary but in some cases can be related to specific conditions caused by a gene mutation (though not a mutation passed on from a parent). In general, they appear because of abnormal blood vessels, or the nerves controlling the widening or narrowing of the blood vessels; or else because of clusters of overgrown pigmented cells. AP

Why do teeth go yellow?

PATRICK LANG, ABERDEEN

Tooth colour is affected by the way that the teeth scatter, reflect and absorb light. As ardent drinkers of coffee and red wine will know, the outer enamel layer of teeth can easily stain, giving teeth a yellow hue. However, what's inside counts too. Since enamel is fairly translucent, the underlying yellow dentin plays a major role in tooth colour. Baby teeth appear white because the dentin is paler in colour, so it doesn't show through the enamel as much. However, our luck runs out with adult teeth. The dentin is darker and enamel tends to thin as we age, letting dentin's colour shine through. Some medications, such as tetracycline antibiotics, are also known to cause teeth to turn yellow. ED

Why do dogs go grey but cats don't?

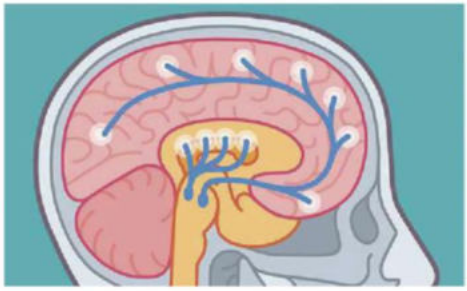
JOHN DUNCAN PAWSON, SCARBOROUGH

Strictly speaking, cats can go grey. Some cats will go grey as they age but not on the scale that dogs and humans do. As our feline friends mature, they retain enough melanocytes – the cells in the hair follicles responsible for the production of the pigment melanin – to ensure that the colouring process does not significantly diminish. We are not sure why this is the case. For example, it is possible that cats are born with a greater number of melanocytes in the first place, or that they simply don't decline at the same rate as they do in dogs. **CC**

PHOTOS: GETTY X3, PRESS ASSOCIATION, ALAMY, SHUTTERSTOCK ILLUSTRATIONS: RAJA LOCKEY

...WHEN I EAT SUGAR?

Sugar is the primary source of energy for your cells. Complex carbohydrates like starch are broken down into simple sugars during digestion and then metabolised by the cells to produce energy. Your blood normally contains 5g of sugar dissolved in it (about a teaspoon). That's only about 20 calories, which is enough for a five-minute walk.

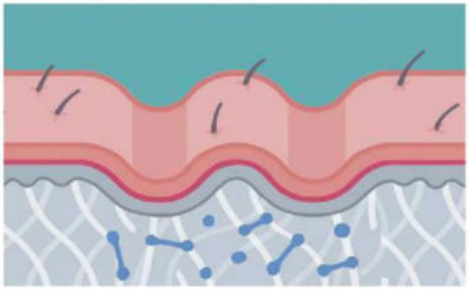


Brain

Sugar causes the brain to release dopamine and opioids – natural pleasure chemicals. Rats on high-sugar diets behave like drug addicts.

Teeth

Bacteria, such as *Streptococcus mutans*, eat leftover sugar in your mouth and ferment it into lactic acid. This dissolves the minerals in your tooth enamel.

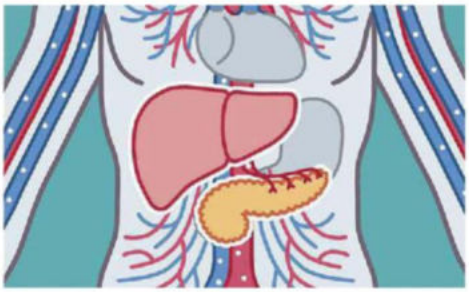


Skin

Glucose and fructose form bonds between amino acids that convert collagen and elastin into substances that cause wrinkles.

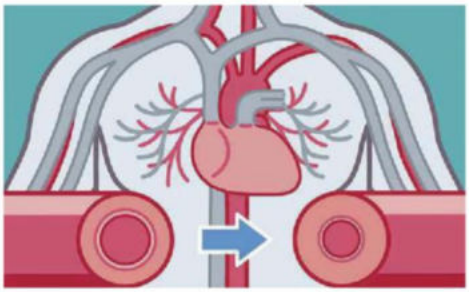
Liver

The liver uses fructose to create fat via a process called lipogenesis. Too much sugar causes a build-up of fat globules called non-alcoholic liver disease.



Pancreas

Rising blood sugar levels stimulate beta cells to secrete insulin. This signals the liver and muscles to start converting glucose into glycogen for storage.



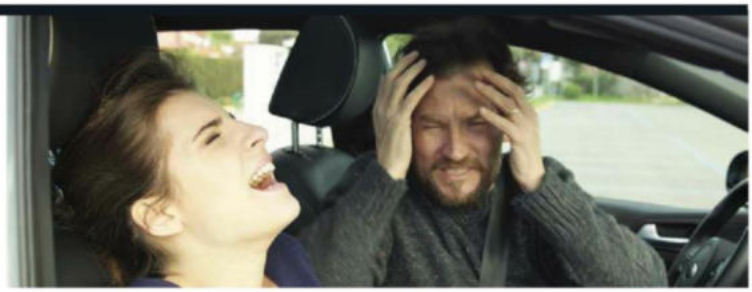
Heart

High insulin levels in the blood cause smooth muscle cells around artery walls to grow faster. This raises blood pressure, eventually leading to heart disease.

Why are some clouds flat underneath?

CHARLIE MACK, UCKFIELD

As warm air rises, the water vapour remains invisible until the air cools enough for it to condense into water droplets. The altitude where that happens marks the bottom of the cloud. Providing that more air feeds in from below, new cloud will form there and preserve the flat bottom. The existing cloud is pushed upwards, forming a fluffy top. LV



Why do we wince when others are in pain?

TIM MADDOX, PETERBOROUGH

Wincing is a form of communication. Rats, rabbits, sheep, horses and pigs all have their own wince expression when they are in pain. This lets other members of their family or herd know that something nearby is dangerous.

Wincing when you see someone else in pain is part of the human ability to empathise. We are social animals, and imagining how those around us might be feeling is part of the emotional 'glue' that keeps us together. **LV**

Salt: tasty on chips and antibacterial to boot!

Why does salt have antibacterial properties?

DAVE CULLIS, LEICESTER

Salt kills some types of bacteria, effectively by sucking water out of them. In a process known as osmosis, water passes out of a bacterium so as to balance salt concentrations on each side of its cell membrane. Without water, bacterial proteins such as enzymes cannot function and eventually the cell collapses in on itself. Some bacteria can tolerate salt; they are halotolerant. Certain strains of *Staphylococcus*, responsible for infections, blood poisoning, and even death, are halotolerant. These pathogens have a salt alert system that uses sponge-like molecules to prevent water loss. **ED**

The Roman theatre at Volterra is currently being immortalised with 3D scanning techniques

How do scientists preserve historic buildings digitally?

CLARE SIMPSON, LONDON

Many important buildings are lost because of natural disasters such as fires and earthquakes. More recently, war and religious conflict have caused the deliberate destruction of thousands of ancient structures. Digital scanning technologies offer one way to preserve our history. They use laser scanning and cameras, sometimes mounted on drones, to take full three-dimensional scans of architecture and artefacts. These can then be reconstructed in a computer to produce identical 3D models complete in every visible detail. Put on a VR headset and you can virtually visit them any time you like. It's a technique being used right now to preserve the 3,000-year-old city of Volterra in Tuscany, Italy. **PB**

Why do people enjoy rollercoaster rides?

COLIN GRAY, BY EMAIL

Some people, especially thrill-seeking extroverts, seem to enjoy rollercoasters because they get to experience the physical sensations of fear while knowing on some level that they are in fact safe (putting aside rare accidents). Psychologists refer to this enjoyment of sensations that are usually considered negative as 'benign masochism' and it seems to be a uniquely human phenomenon. In the case of rollercoasters, these sensations are fear-related, but other examples of benign masochism include the enjoyment of sad and scary films, disgusting jokes and painfully spicy chillies. The enjoyment of rollercoasters may be distinct from the pleasure some people get from extreme sports where the fear and risk of danger is entirely real. CJ

PHOTOS: GETTY X2, SILVIU STOIAN/BECK GROUP/THE VOLTERRA-DETROIT FOUNDATION ILLUSTRATIONS: RAJA LOCKEY

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TOP 10

BIGGEST CO_2 EMITTERS IN 2016

(MILLIONS OF METRIC TONNES)

1. China
10,212 (28.21%)

2. USA
5,788 (15.99%)

3. India
2,259 (6.24%)

4. Russia
1,640 (4.53%)

5. Japan
1,329 (3.67%)

6. Germany
807 (2.23%)

7. South Korea
634 (1.75%)

8. Iran
623 (1.72%)

9. Canada
619 (1.71%)

10. Saudi Arabia
565 (1.56%)

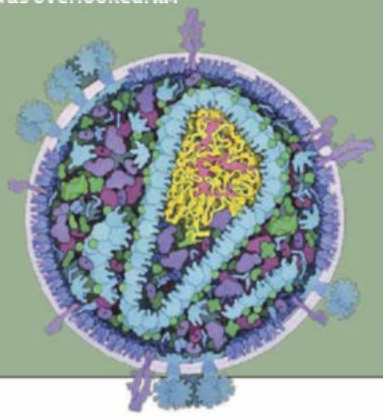
WHO REALLY DISCOVERED?

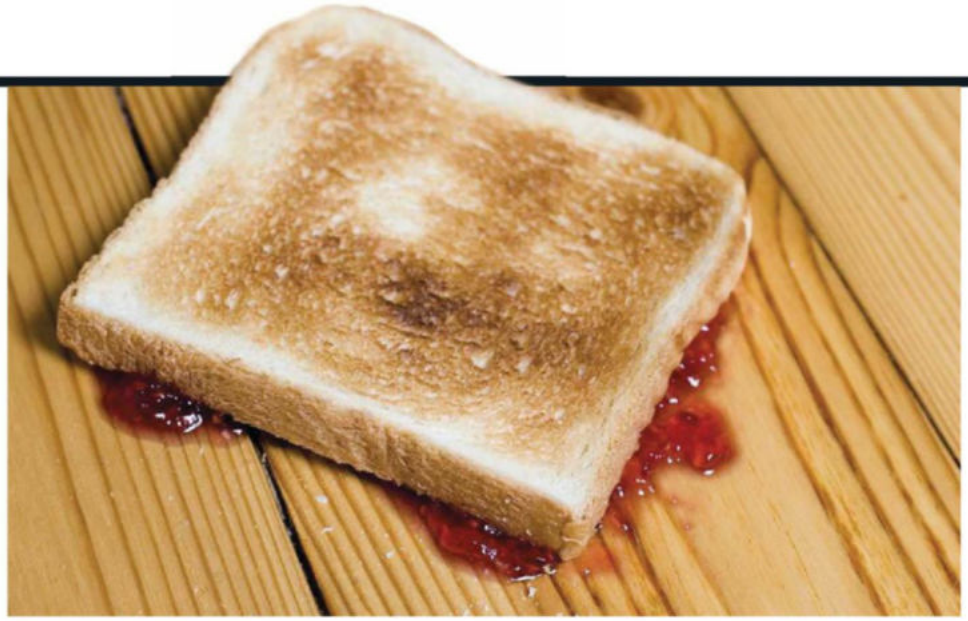
HIV

ROBERT GALLO

LUC MONTAGNIER

In May 1983, two papers appeared in the same issue of *Science* claiming the same breakthrough: the identification of a virus apparently linked to AIDS. While neither the US nor the French teams were certain of the link, their claims were seized on in the search for a treatment. Further research by the US team confirmed the AIDS connection, and the virus was named the Human Immunodeficiency Virus (HIV). But the coincidence of two teams making the same claim sparked a bitter row between the team leaders: Robert Gallo of the National Cancer Institute, Maryland, and Luc Montagnier of the Pasteur Institute, Paris. Initially the dispute focused on who should benefit from royalties for a blood test for HIV. In 1987, the US and French governments settled that dispute by declaring both teams co-discoverers. But then Gallo's team were accused of having wrongfully acquired the virus from the Paris team – a charge later rejected by investigators. The arguments continued until 2002, when the rivals publicly agreed that Montagnier's team had discovered HIV, but its role in AIDS was first shown by Gallo. Even so, controversy flared once more in 2008 when the Nobel prize was awarded for the HIV breakthrough – and Gallo's contribution was overlooked. **RM**





Why does toast often land butter-side down?

COCO SHANG, SEVENOAKS

For years this notorious example of Murphy's Law – 'If something can go wrong, it will' – was dismissed by scientists who insisted toast was as likely to land butter-side up as down. Then, in 1996, I published a theoretical analysis of toast falling off a plate that suggested there should be a bias towards butter-side down landings. In 2001, a nationwide experiment involving over 1,000 schoolchildren and 21,000 drops of toast confirmed the theory: toast falling off a plate lands butter-side down almost two-thirds of the time. Contrary to common belief, it's nothing to do with one side being buttered. The explanation is that as the toast goes over the edge of the plate, it starts to rotate, but the spin-rate is too slow to bring the butter-side uppermost again by the time the toast hits the floor. **RM**

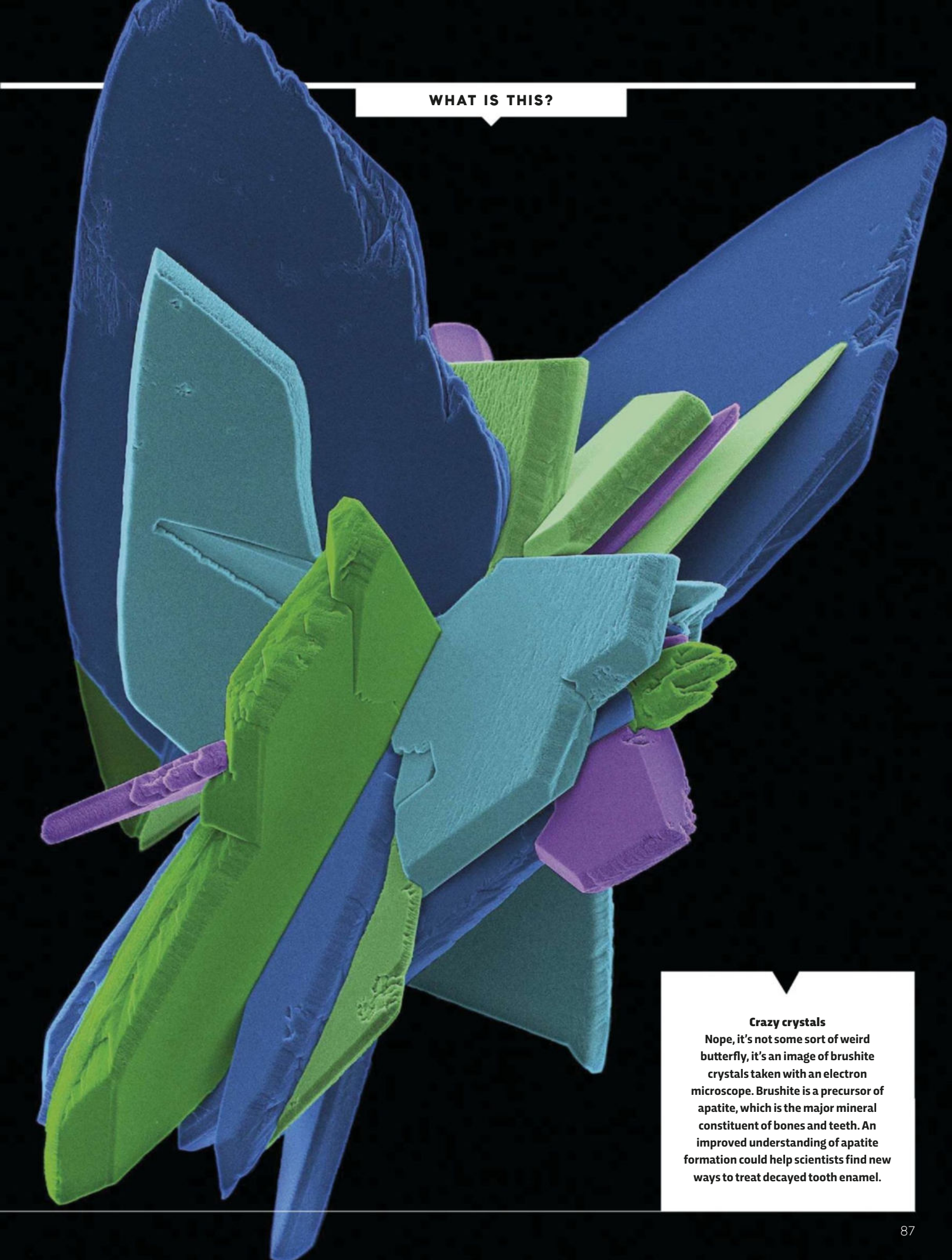
Is climate change going to make flights bumpier?

EDDIE LANE, SHEFFIELD

Images of the aftermath of turbulence battering an Aeroflot flight to Bangkok earlier this year raised questions about whether climate change might make such incidents more common. And, according to new research by Dr Paul Williams of the University of Reading, the answer is yes. Computer simulations suggest global warming will create stronger crosswinds in the high atmosphere – making severe turbulence much more likely. **RM**

PHOTOS: GETTY X4, DAVID S GOODSELL, SCIENCE PHOTO LIBRARY

WHAT IS THIS?



Crazy crystals
Nope, it's not some sort of weird butterfly, it's an image of brushite crystals taken with an electron microscope. Brushite is a precursor of apatite, which is the major mineral constituent of bones and teeth. An improved understanding of apatite formation could help scientists find new ways to treat decayed tooth enamel.

Do animals experience love?

REBECCA POLLARD, WAKEFIELD

Neuroscience tells us that many animals possess the physiological attributes needed to enable them to experience love, if defined as 'feelings of strong affection for a particular individual'. Research shows that the 'cuddle hormone' oxytocin is heightened in dogs when they are interacting with their owners, which increases bonding. Paired prairie voles stay together thanks to the 'desire' hormone dopamine, which they are more receptive to after mating. Behaviourally we see animals displaying extraordinary evidence of grief, care and empathy towards each other and their human companions – this clearly isn't just 'cupboard love'! If they could talk, I believe they absolutely would say they can and do love. **CC**

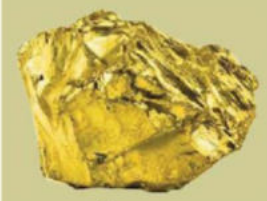
How will driverless cars avoid potholes?

GREG SMITH, MANCHESTER

The best driverless cars, such as Google's Waymo, are aiming for level 4 autonomy – this means they will take over driving in certain locations under certain weather conditions. To achieve this, cars have sensors such as LiDAR (which pulses lasers at objects and measures reflections to calculate their distances) in addition to GPS, inertia measurement, radar and cameras. Even if the driverless cars could detect potholes – which may not be possible in all weather conditions – it may be dangerous for them to avoid them, so it is more likely that they will simply drive slower. Recent reports suggest that our entire road network may need to be upgraded at a cost of billions, otherwise driverless vehicles may all be forced to crawl along in 'proceed with caution' mode. PB

WHAT CONNECTS...

...GOLD AND BABY HAIR?



1. As gold is unreactive, it exists as nanoparticles in seawater and the soil. Plants and animals absorb some of these gold nanoparticles, so they pass up the food chain to us.

2. Even if you don't have any gold fillings, there is about 2mg of gold in your body. If you could somehow extract this, it would be worth just over 6p.

3. Our bodies carefully regulate the concentrations of biologically active metals such as zinc and copper and remove any surplus via the skin and hair. Gold, though harmless, is excreted the same way.

4. Babies under three months have more gold in their hair than older people. This comes from their mother's breast milk and can reach double the average concentration of gold in Earth's crust.

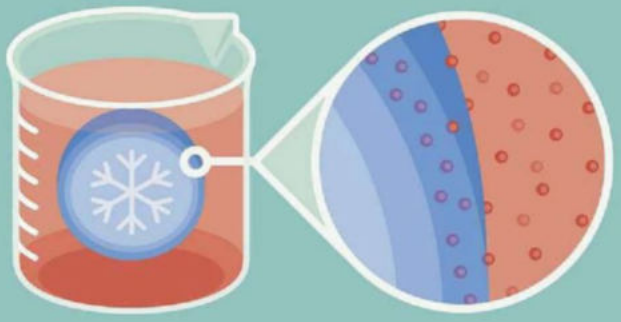
PHOTOS: GETTY X5, AUBREY KELLY/CORNELL UNIVERSITY ILLUSTRATIONS: RAJA LOCKEY

EDIBLE WATER BOTTLES

Edible liquid bubbles were originally developed for molecular gastronomy chef Ferran Adrià. Now, start-up company Skipping Rocks Lab has turned this into Ooho! – a bite-sized blob of water. The water is contained in an edible membrane that is made from two tasteless ingredients: sodium alginate (usually derived from seaweed) and calcium chloride. Both are already used in the food industry and are completely safe. Currently, the membrane only lasts a few days before breaking down but the developers are working on tougher versions that could be licensed to drinks companies.

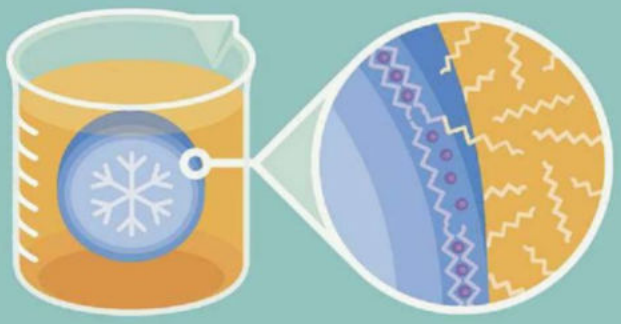
1. SHAPE
Water is frozen into a ball so that it holds its shape, and to keep the water molecules from mixing with the membrane chemicals.

2. DIP
The ice ball is dipped into calcium chloride solution. The outer layer of ice melts and some of the calcium ions diffuse in.



3. ALGINATE
A second bath in warm sodium alginate solution forms the membrane. Calcium ions replace sodium atoms in the alginate and bind the molecules together.

4. POLYMER
Unlike sodium, calcium has two positive charges. This lets it bond to two alginate chains at once, tangling them up.



5. THAW
After two to five minutes, enough of the alginate molecules have polymerised together to form a stable skin and the ice melts into a liquid centre.

Why do people whistle?

TONY WEBB, LANGFORD

Apart from a small study from 2011 that found men whistle more than women, there's actually remarkably little psychology research on whistling. However, music is a human universal found all over the world and whistling is just another form of what music scholars call 'momentary musical performing', alongside singing in the shower, drumming a beat on the desk and humming while you do the housework, with the choice of tune likely reflecting our mood or perhaps chosen in an attempt to enhance it. Whistling is something we especially tend to do when we're bored. CJ

NEXT ISSUE:

Do trees reduce air pollution?

Do seagulls drink seawater?

How does exercise reduce stress?

Email your questions to **questions@sciencefocus.com** or submit online at **sciencefocus.com/qanda**

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

SUMMER 2017 | EDITED BY JAMES LLOYD

01

WHALES: BENEATH THE SURFACE
NATURAL HISTORY MUSEUM, LONDON,
14 JULY 2017 – 28 FEB 2018.
NHM.AC.UK/WHALES

HAVE A WHALE OF A TIME

From this month, visitors to London's Natural History Museum will be greeted by a spectacular sight. Diving through the centre of the Hintze Hall will be the skeleton of a blue whale – the largest animal known ever to have graced our planet.

The real, 25.2m-long female skeleton will take centre stage in the hall among hundreds of new specimens, replacing the much-loved dinosaur, Dippy, who embarks on a UK tour from February 2018.

The reopening of the hall coincides with *Whales: Beneath The Surface*, a new exhibition celebrating these giants of the deep, alongside the other members of their family: dolphins and porpoises. Skulls, flippers and jawbones will show how whales swim, breathe and feed, while an immersive experience reveals how some of these animals are able to sense their prey using sound.

The Hintze Hall and the new exhibition both open on 14 July 2017.

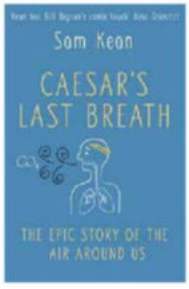
PHOTO: TONY WU/NATUREPL.COM

02

SHARE A BREATH WITH CAESAR

With every breath, we inhale the story of our planet. SAM KEAN, author of *Caesar's Last Breath*, tells us about the remarkable history of the air around us

CAESAR'S LAST BREATH
BY SAM KEAN
OUT 20 JULY (£20, DOUBLEDAY).



Are we really breathing in some of Caesar's last breath?
The story goes that in 44 BC in Rome, Julius Caesar was assassinated by a group of his own senators, crumpling to the floor with a final gasp. This last breath contained around 25 sextillion (that's 25 followed by 21 zeroes) air molecules, which would have spread around the globe within a couple of years. A breath seems like such a small thing compared to the Earth's atmosphere, but remarkably, if you do the math, you'll find that roughly one molecule of Caesar's air will appear in your next breath.

And it doesn't stop there. In the same way, you might currently be inhaling Cleopatra's perfume, German mustard gas and even particles exhaled by dinosaurs.

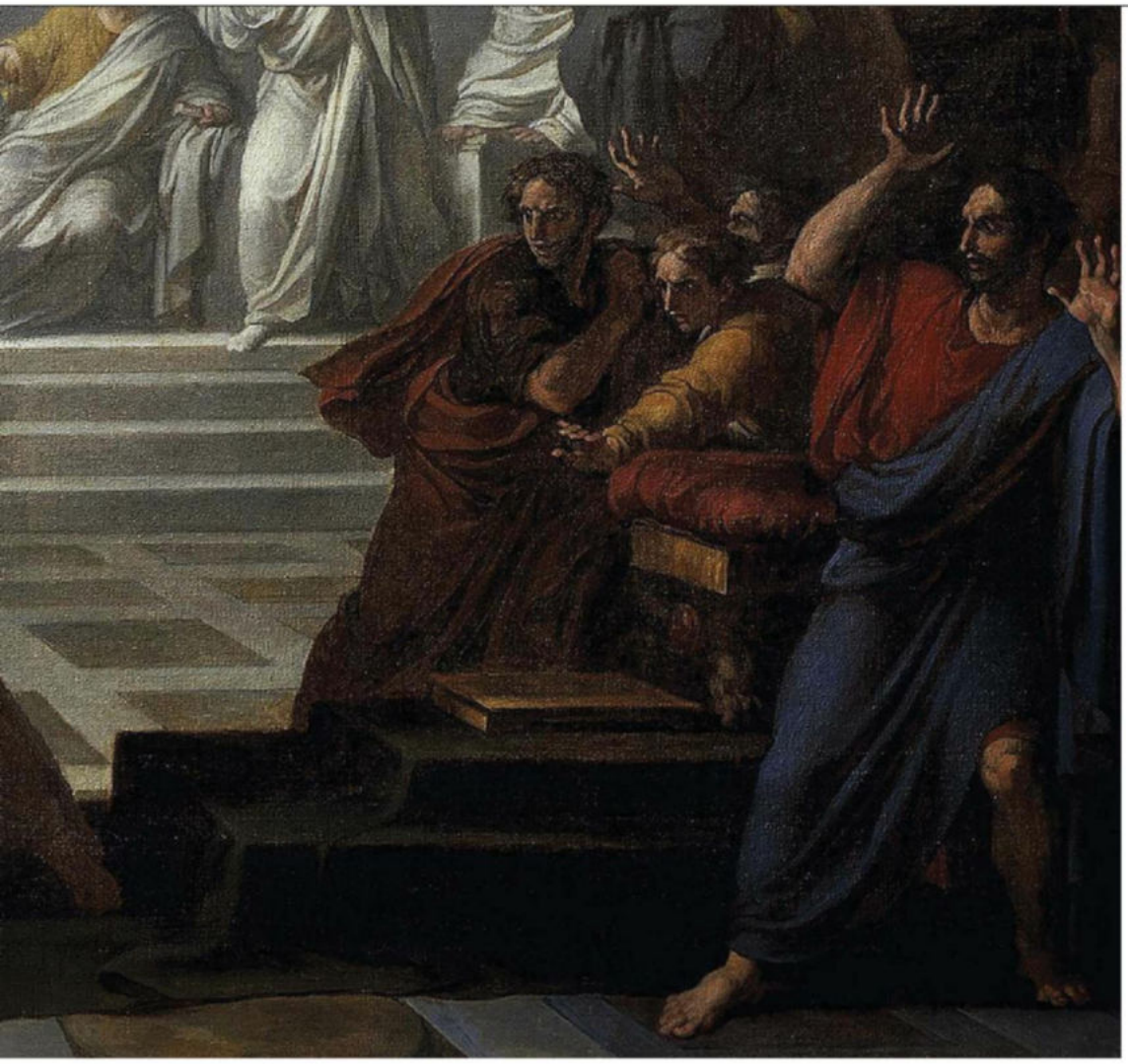
What exactly are these air molecules?
Nitrogen and oxygen are the main ingredients of air, making up 99 per cent, but that extra 1 per cent is still really important. It's like a glass of wine: most of the wine is alcohol and water, but there are all these extra overtones and flavours, too. In air, this 1 per cent is responsible for all of global warming as well as all scents and perfumes. It includes carbon dioxide, nitrous oxide (laughing gas), assorted pollutants and volcano exhaust.

The ingredients of air reveal the world's entire history. Some of them have been around since the early days of the planet, while some only arose with the arrival of life, or with human civilisation.

Where did our atmosphere come from?
We've actually had four different atmospheres in the Earth's history. The first was a wispy leftover from our planet's formation, and soon got blown away. The next came from the ground, seeping out of cracks in the Earth's surface – mostly carbon dioxide and water vapour, but also gases such as sulphur dioxide and hydrogen sulphide. Atmosphere number three was dominated by nitrogen, emitted from volcanic vents in relatively small quantities, but capable of sticking around for a long time. And finally, oxygen began to build up in the atmosphere thanks to early, photosynthesising life forms. This paved the way for an oxygen-rich atmosphere that could support complex life.

If you wanted to travel back in a time machine to the Earth's distant past and take a deep breath outside, you'd only be able to go back a few hundred million years – it's only very recently in our planet's history that there's been enough oxygen to sustain us.

PHOTOS: GETTY X2



Julius Caesar has been dead for 2,061 years, but the air he breathed is still in circulation

How is the air we breathe changing?
The atmosphere is like a living thing – it's constantly evolving. The rates of carbon dioxide and other greenhouse gases are increasing, and the air is more radioactive now because we're still dealing with fallout from 1950s nuclear weapons tests.

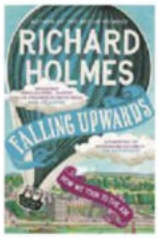
We also see a lot more complex, human-made molecules in the air today. If aliens were to look at our planet's atmosphere, the presence of these gases would be a good sign that the Earth harbours life. Likewise, the next generation of telescopes should allow us to start looking for these complicated gases in the atmospheres of distant exoplanets, helping us to search for the best candidates for extraterrestrial life.

I think it's also inevitable that we'll find an exoplanet with a great mix of gases for us to survive on. The hard part will be figuring out how to get there.

What other interesting stories did you uncover about the air?
One of my favourites involves Charles Dickens. In his 1853 novel *Bleak House*, a character called Krook appears to spontaneously combust, turning into a pile of ash. At the time, scientists were beginning to figure out how breathing works, and they were also starting to make connections between burning and the oxygen in air. So some people thought that if we have a lot of oxygen in our bodies, maybe we could spontaneously ignite. It's possible that these ideas influenced Dickens, along with eyewitness accounts. But now, of course, we know it's not possible. The body is up to 75 per cent water, and even the worst fever doesn't get us hot enough to start a fire.

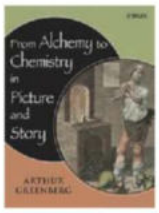
AUTHOR'S BOOKSHELF

Three books that inspired Sam Kean while writing *Caesar's Last Breath*



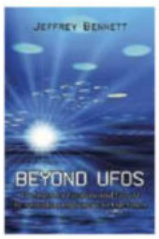
FALLING UPWARDS
BY RICHARD HOLMES
(£10.99, WILLIAM COLLINS)

"Holmes writes the best kind of science books, capturing exactly the wonder and awe that attract people to science, and that help pack museums and natural parks around the world. This book resurrects the miracle of flight in the days before airplanes."



FROM ALCHEMY TO CHEMISTRY IN PICTURE AND STORY
BY ARTHUR GREENBERG
(£88.50, WILEY)

"A fascinating book about the painful, complicated, and sometimes amusing transition that turned disreputable alchemists into the lions of modern chemistry. Encyclopaedic and lavishly illustrated."



BEYOND UFOS
BY JEFFREY BENNETT
(£18.95, PRINCETON UNIVERSITY PRESS)

"The first signs of alien life almost certainly won't be hovering UFOs, but subtle traces of gases in the atmospheres of distant planets. Bennett's book captures the magnitude of the quest for alien life, and its incredible implications for humanity."

03 BECOME A GONZOVATIONIST

Bumblebees are a familiar and endearing sight in our gardens, but they're in trouble. With changing agricultural practices removing wildflowers from the landscape, many of the UK's 24 bumblebee species are in decline, and two have become extinct since the start of the 20th Century.

But the bumblebee is far from alone. A new book by cartoonist Ralph Steadman and film-maker Ceri Levy features more than 100 illustrations of critically endangered animals, alongside fact files, notes, a few cheeky nonsense beasts and a diary of the authors' creative process.

Steadman was originally labelled a 'gonzo' artist, and is best known for his iconic illustrations in Hunter S Thompson's *Fear And Loathing In Las Vegas*. Here, his wonderfully idiosyncratic style captures the animals in a way no camera could, his paintings positively fizzing off the page.

CRITICAL CRITTERS
BY RALPH STEADMAN & CERI LEVY
OUT 27 JULY (£35, BLOOMSBURY).

04

WILD ALASKA LIVE
BBC ONE IN JULY.
(CHECK **RADIOTIMES.COM** FOR DETAILS)

GO BEAR WATCHING...

We're going on a bear hunt… in the wilds of Alaska. Every summer, the annual salmon run kicks off a feeding frenzy, with black bears, brown bears, Kodiak bears, beavers, salmon sharks, bald eagles and wolves all joining in the feast.

Over the course of three nights in July, Steve Backshall, Matt Baker and Liz Bonnin will broadcast live from North America's last frontier, giving us a unique view of this wildlife spectacular. Matt and Liz will be based in Tongass National Forest and Katmai National Park respectively, while Steve will embark on some hair-raising expeditions, attempting to land a helicopter on a moving glacier, and heading offshore to seek out two of our planet's largest predators – orcas and humpback whales.

Two years on from *Big Blue Live*, this looks set to be the BBC Natural History Unit's most ambitious live project yet.

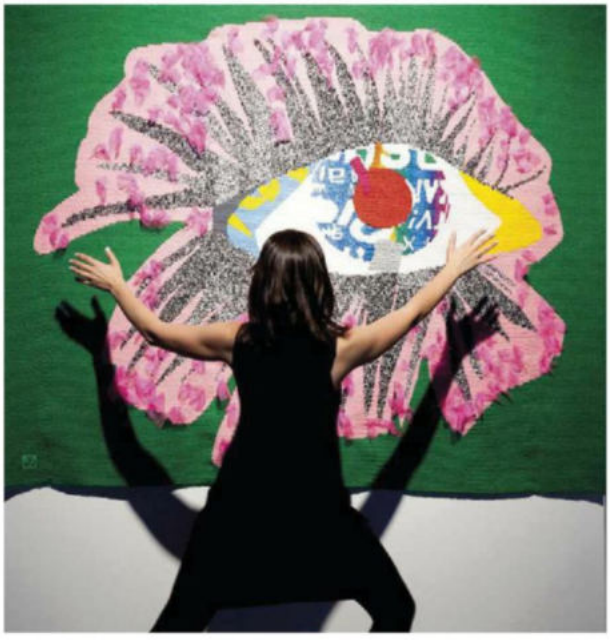
05

SOUND CHECK
SCIENCE GALLERY, DUBLIN, UNTIL 24 SEPT 2017.
DUBLIN.SCIENCEGALLERY.COM/SOUNDCHECK

MAKE SOME NOISE

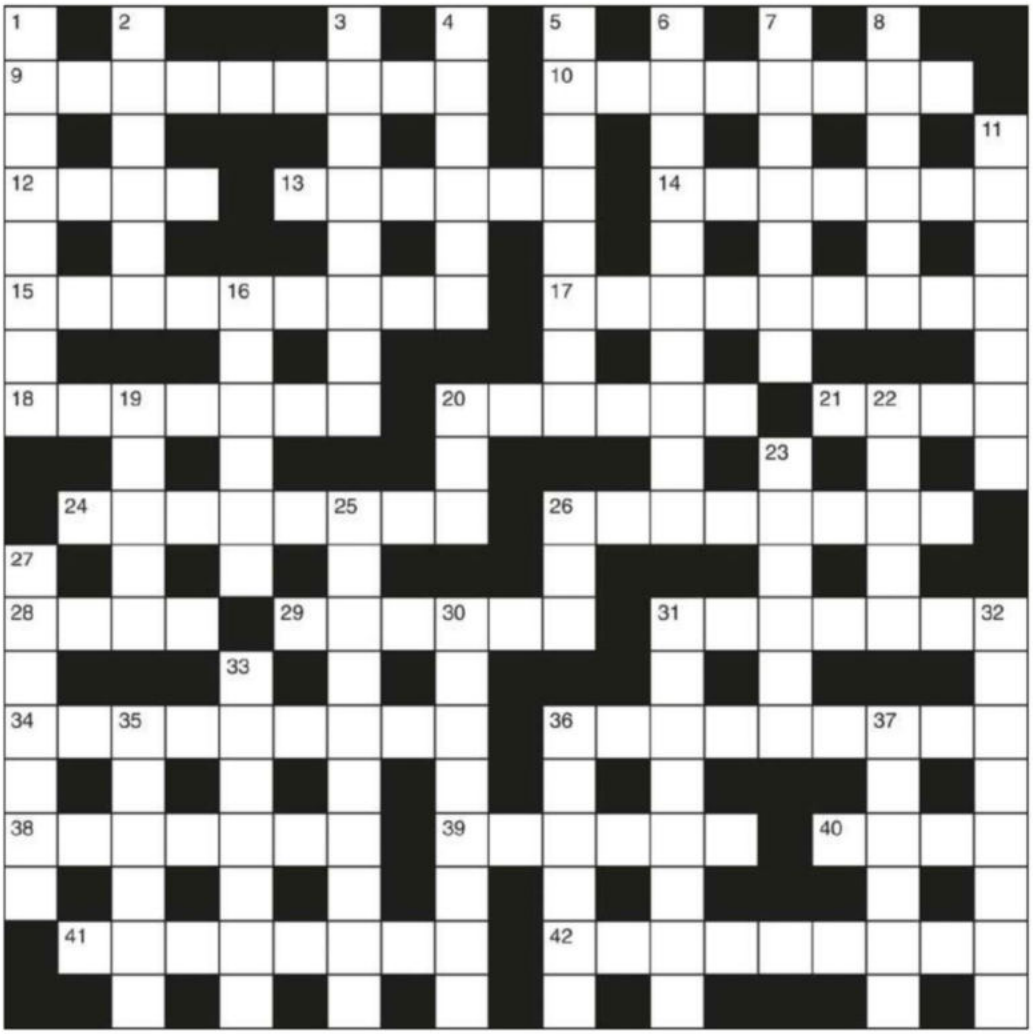
These days, you don't have to be a trained musician to lay down some top-notch tunes. Thanks to software such as GarageBand and Ableton Live, and gadgets ranging from homemade synths to MIDI controllers, anyone can have a go at making music.

Sound Check, a new free exhibition at Dublin's Science Gallery, explores this blossoming relationship between technology and music. In the Noise Studio, visitors will be able to invent their own instruments, bringing them to life using electronics and cardboard. Elsewhere, there are sonic bikes which compose their own tunes as they're pedalled through the streets of Dublin, a set of swings that create harmonies as people rock back and forth, and a 'theremin tapestry' that wibbles and warbles as you move in front of it. If this is the future of music, count us in.



PHOTOS: CERI LEVY, ALAMY

SCIENCE CROSSWORD
GIVE YOUR BRAIN A WORKOUT



ACROSS

9 Lump of rock makes hotel a bit dilapidated (9)
10 I will yearn outwardly to get a plant (8)
12 Brooding about god (4)
13 Nose on your first comic strip character (6)
14 Stop my transformation to medium manifestation (7)
15 Frequency of seeing huge bike (9)
17 Hate a menu devised in institute of learning (9)
18 Miss performance in sugar (7)
20 Terrible hack takes artist to major energy centre (6)
21 Irritating woman takes hard currency (4)
24 Set of characters laugh during a record wager (8)
26 Evil bats ruin Isle of Wight event (8)
28 The shape of cricket in London (4)
29 Quick to photograph pretty edges (6)
31 Cited problem with a student jargon (7)
34 Notes, terribly queer, left some radioactivity (9)
36 Bird has filed away ticket money (9)
38 Strike-breaker is catching English disease (7)
39 Crush a vegetable (6)
40 Voice changes a lot (4)
41 Legacy affected their time (8)
42 Old port may get repeatedly bitter (9)

DOWN

1 Sailor finds two chaps different (8)
2 Fastening in series (6)
3 Clean out receptacle first for compass housing (8)
4 Mad poet takes back the old cactus (6)
5 About soldier getting by returning rodent (8)
6 Shop around with quiet deity for element (10)
7 Only aim – repair and maintenance (7)
8 One insect let off another (6)
11 Aim to move friend to Islamic territory (7)
16 Almost notice fellow in hat (6)
19 Eyelashes sound more ridiculous (5)
20 Scan for a feline (3)
22 First character donated a plant (5)
23 Reptile seen at our lowest point (6)
25 Celebrity in base two forms double act (6,4)
26 Hygiene problem unknown to youngster (3)
27 Two doctors when reaching a port (7)
30 Pet rolls around for opinion seeker (8)
31 Wise man follows Reds playing sport (8)
32 Heard character get full without alcohol (8)
33 Limb treated around university – one with a disorder (7)
35 Gossip about the French villa (6)
36 Quarrel with a novice in old social system (6)
37 Everyone has hesitation about one plant genus (6)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW** Please be aware the website address is case-sensitive.

"I love it because it's so remote. It used to take me three days to forget about the rest of the world"

Dame Jane Francis, director of the British Antarctic Survey, tells **Helen Pilcher** about the pleasures of polar research, and how not to make ice cream in Antarctica

What do you do?
It's my job to provide leadership to the international polar community and to manage and represent the British Antarctic Survey. That includes overseeing all of our science, our research stations in Antarctica, the people who live and work there, and our aircraft and ships. We currently have two ships, and the *RRS Sir David Attenborough* which is being built.

And the infamous Boaty McBoatface?
Yes. Boaty McBoatface was the name given to the small robotic subs that will be launched from the ship. The original naming competition was run by the Natural Environment Research Council, of which we are part. I think it's great that Boaty will be gliding through the oceans collecting important data to help explain the role of oceans in climate change.

How many times have you been to Antarctica?
I've lost count. I'm a geologist by training. I used to go on regular field trips and spend months at a time living in a tent. Fifty million years ago, the climate was much warmer and Antarctica was covered in dense, green forests. I'd go looking for plant fossils from this time. If we want to understand future climate change, it's important to learn from the past.

What's it like working in such an extreme location?
I love it because it's so remote. The tents, which are similar to the ones that early polar explorers used, are snug and windproof. It used to take me around three days to really forget about the rest of the world. After that, the only things I'd concentrate on were my work, the weather – because it can change so suddenly – and what we were going to have for dinner that night. Food became a major preoccupation.

What's a typical meal in the Antarctic?
It varies. Breakfast would be sugary porridge, washed down by loads of tea to avoid dehydration. Then we'd walk for miles to make observations and collect rocks, and stop in a sheltered gully for a lunch of maybe biscuits, canned cheese and Marmite… and lots of milk chocolate. Then we'd cook in the tent in the evening. One of the things you notice is that you lose your sense of taste. We end up putting tonnes of curry powder in our food to make it really punchy.

Any puddings? Arctic roll?
I did try to make ice cream once. I mixed milk powder, a bottle of vanilla essence and water then put it outside the tent to freeze. At -25°C, we figured it would be ready in about five minutes, but half an hour later it was still runny. In the end, we left it outside for a week, and it still didn't set. We later discovered it was synthetic vanilla, essentially made from antifreeze chemicals. We found it funny that we couldn't make ice cream in Antarctica!

How does one go to the toilet in Antarctica?
We have a small toilet tent on the edge of camp that has a special plastic tub with a seat on. When the tub is full it's sealed then taken away from Antarctica and incinerated. There are strict environmental laws to make sure that we leave Antarctica as beautiful and pristine as we find it.

Prof Jane Francis is the director of the British Antarctic Survey. In 2017 she became a dame, in recognition of her outstanding contribution to polar science.

DISCOVER MORE

To listen to an episode of *The Life Scientific* with Dame Jane Francis visit **bit.ly/Jane_francis**

NEXT ISSUE: BRENNA HASSETT

ILLUSTRATION: DAVID DESPAU

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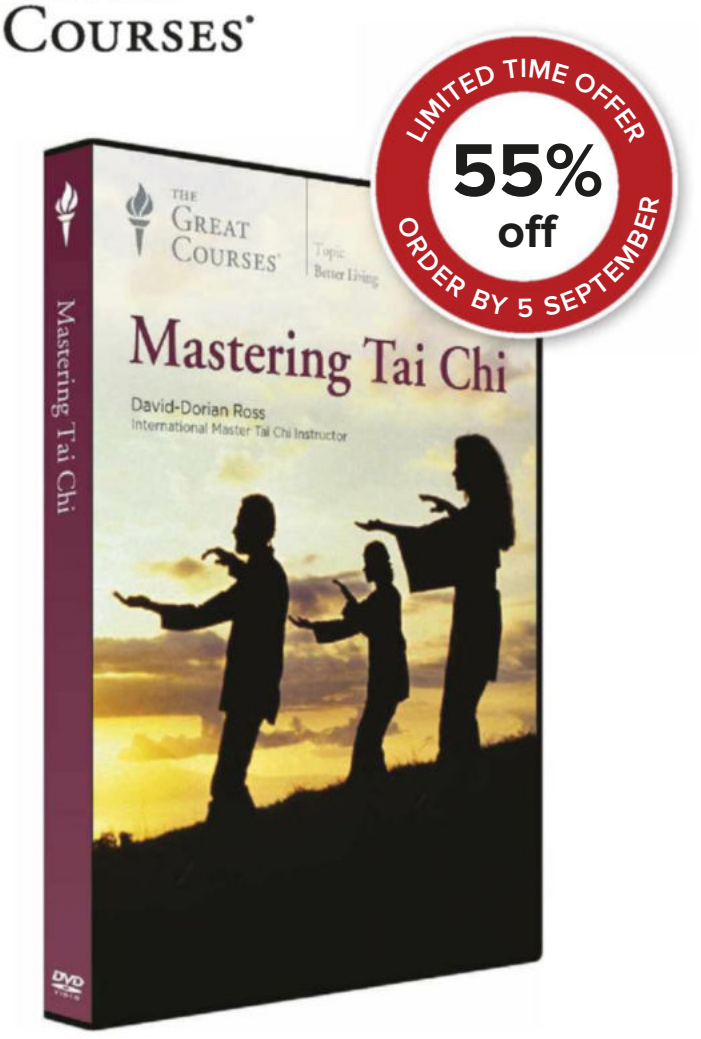

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10. Shoulders: Finding Reasons to Let Go
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